SAVE-IT

# SAfety VEhicles using adaptive Interface Technology (Task 2a)

## USING MICHIGAN HIGHWAY SAFETY INFORMATION SYSTEM (HSIS ) DATA FOR ESTIMATING DRIVING TASK DEMAND

Prepared by


David W. Eby, Ph.D.
UMTRI
Phone: (734)-763-2466
Email: eby@umich.edu

Lidia P. Kostyniuk, Ph.D.
UMTRI
Phone: (734)-763-2466
Email: lidakost@umich.edu


November 2004

TABLE OF CONTENTS

# 2.0 Program Overview

Driver distraction is a major contributing factor to automobile crashes. National Highway Traffic Safety Administration (NHTSA) has estimated that approximately 25% of crashes are attributed to driver distraction and inattention (Wang, Knipling, & Goodman, 1996). The issue of driver distraction may become worse in the next few years because more electronic devices (e.g., cell phones, navigation systems, wireless Internet and email devices) are brought into vehicles that can potentially create more distraction. In response to this situation, the John A. Volpe National Transportation Systems Center (VNTSC), in support of NHTSA's Office of Vehicle Safety Research, awarded a contract to Delphi Electronics & Safety to develop, demonstrate, and evaluate the potential safety benefits of adaptive interface technologies that manage the information from various in-vehicle systems based on real-time monitoring of the roadway conditions and the driver's capabilities. The contract, known as SAfety VEhicle(s) using adaptive Interface Technology (SAVE-IT), is designed to mitigate distraction with effective countermeasures and enhance the effectiveness of safety warning systems.

The SAVE-IT program serves several important objectives. Perhaps the most important objective is demonstrating a viable proof of concept that is capable of reducing distraction-related crashes and enhancing the effectiveness of safety warning systems. Program success is dependent on integrated closed-loop principles that, not only include sophisticated telematics, mobile office, entertainment and safety warning systems, but also incorporate the state of the driver. This revolutionary closed-loop vehicle environment will be achieved by measuring the driver’s state, assessing the situational threat, prioritizing information presentation, providing adaptive countermeasures to minimize distraction, and optimizing advanced collision warning.

To achieve the objective, Delphi Electronics & Safety has assembled a comprehensive team including researchers and engineers from the University of Iowa, University of Michigan Transportation Research Institute (UMTRI), General Motors, Ford Motor Company, and Seeing Machines, Inc. The SAVE-IT program is divided into two phases shown in Figure i. Phase I spans one year (March 2003--March 2004) and consists of nine human factors tasks (Tasks 1-9) and one technology development task (Task 10) for determination of diagnostic measures of driver distraction and workload, architecture concept development, technology development, and Phase II planning. Each of the Phase I tasks is further divided into two sub-tasks. In the first sub-tasks (Tasks 1, 2A-10A), the literature is reviewed, major findings are summarized, and research needs are identified. In the second sub-tasks (Tasks 1, 2B-10B), experiments will be performed and data will be analyzed to identify diagnostic measures of distraction and workload and determine effective and driver-friendly countermeasures. Phase II will span approximately two years (October 2004--October 2006) and consist of a continuation of seven Phase I tasks (Tasks 2C--8C) and five additional tasks (Tasks 11-15) for algorithm and guideline development, data fusion, integrated countermeasure development, vehicle demonstration, and evaluation of benefits.

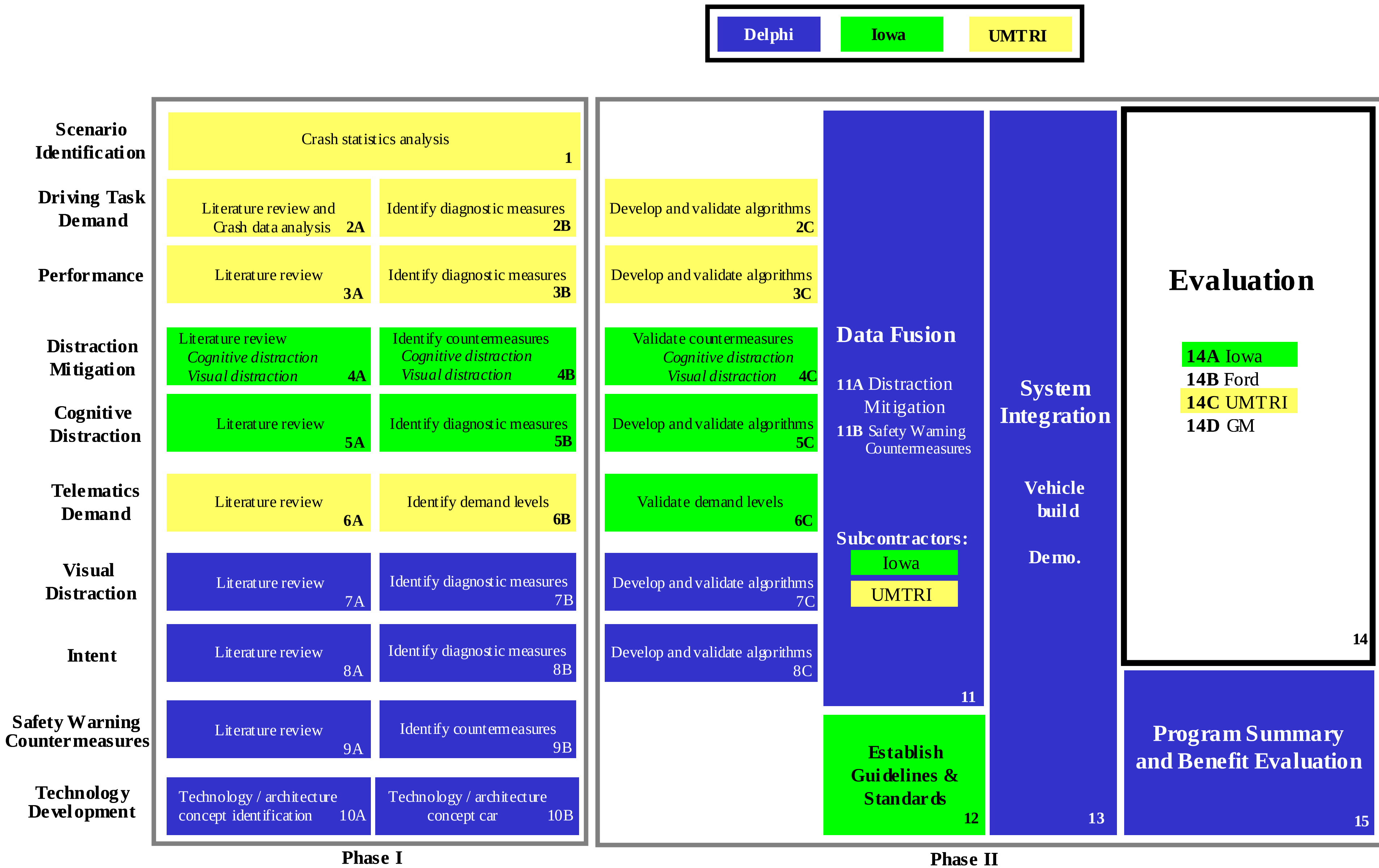


Figure i: SAVE-IT tasks

It is worthwhile to note the SAVE-IT tasks in Figure i are inter-related. They have been chosen to provide necessary human factors data for a two-pronged approach to address the driver distraction and adaptive safety warning countermeasure problems. The first prong (Safety Warning Countermeasures sub-system) uses driver distraction, intent, and driving task demand information to adaptively adjust safety warning systems such as forward collision warning (FCW) systems in order to enhance system effectiveness and user acceptance. Task 1 is designed to determine which safety warning system(s) should be deployed in the SAVE-IT system. Safety warning systems will require the use of warnings about immediate traffic threats without an annoying rate of false alarms and nuisance alerts. Both false alarms and nuisance alerts will be reduced by system intelligence that integrates driver state, intent, and driving task demand information that is obtained from Tasks 2 (Driving Task Demand), 3 (Performance), 5 (Cognitive Distraction), 7 (Visual Distraction), and 8 (Intent).

The safety warning system will adapt to the needs of the driver. When a driver is cognitively and visually attending to the lead vehicle, for example, the warning thresholds can be altered to delay the onset of the FCW alarm or reduce the intrusiveness of the alerting stimuli. When a driver intends to pass a slow-moving lead vehicle and the passing lane is open, the auditory stimulus might be suppressed in order to reduce the alert annoyance of a FCW system. Decreasing the number of false positives may reduce the tendency for drivers to disregard safety system warnings. Task 9 (Safety Warning Countermeasures) will investigate how driver state and intent information can be used to adapt safety warning systems to enhance their effectiveness and user acceptance. Tasks 10 (Technology Development), 11 (Data Fusion), 12 (Establish Guidelines and Standards), 13 (System Integration), 14 (Evaluation), and 15 (Program Summary and Benefit Evaluation) will incorporate the research results gleaned from the other tasks to demonstrate the concept of adaptive safety warning systems and evaluate and document the effectiveness, user acceptance, driver understandability, and benefits and weaknesses of the adaptive systems. It should be pointed out that the SAVE-IT system is a relatively early step in bringing the driver into the loop and therefore, system weaknesses will be evaluated, in addition to the observed benefits.

The second prong of the SAVE-IT program (Distraction Mitigation sub-system) will develop adaptive interface technologies to minimize driver distraction to mitigate against a global increase in risk due to inadequate attention allocation to the driving task. Two examples of the distraction mitigation system include the delivery of a gentle warning and the lockout of certain telematics functions when the driver is more distracted than what the current driving environment allows. A major focus of the SAVE-IT program is the comparison of various mitigation methods in terms of their effectiveness, driver understandability, and user acceptance. It is important that the mitigation system does not introduce additional distraction or driver frustration. Because the lockout method has been shown to be problematic in the aviation domain and will likely cause similar problems for drivers, it should be carefully studied before implementation. If this method is not shown to be beneficial, it will not be implemented.

The distraction mitigation system will process the environmental demand (Task 2: Driving Task Demand), the level of driver distraction [Tasks 3 (Performance), 5 (Cognitive Distraction), 7 (Visual Distraction)], the intent of the driver (Task 8: Intent), and the telematics distraction potential (Task 6: Telematics Demand) to determine which functions should be advised against under a particular circumstance. Non-driving task information and functions will be prioritized based on how crucial the information is at a specific time relative to the level of driving task demand. Task 4 will investigate distraction mitigation strategies and methods that are very well accepted by the users (i.e., with a high level of user acceptance) and understandable to the drivers. Tasks 10 (Technology Development), 11 (Data Fusion), 12 (Establish Guidelines and Standards), 13 (System Integration), 14 (Evaluation), and 15 (Program Summary and Benefit Evaluation) will incorporate the research results gleaned from the other tasks to demonstrate the concept of using adaptive interface technologies in distraction mitigation and evaluate and document the effectiveness, driver understandability, user acceptance, and benefits and potential weaknesses of these technologies.

In particular, driving task demand and driver state (including driver distraction and impairment) form the major dimensions of a driver safety system. It has been argued that crashes are frequently caused by drivers paying insufficient attention when an unexpected event occurs, requiring a novel (non-automatic) response. As displayed in Figure ii, attention to the driving task may be depleted by driver impairment (due to drowsiness, substance use, or a low level of arousal) leading to diminished attentional resources, or allocation to non-driving tasks[1]. Because NHTSA is currently sponsoring other impairment-related studies, the assessment of driver impairment is not included in the SAVE-IT program at the present time. One assumption is that safe driving requires that attention be commensurate with the driving demand or unpredictability of the environment. Low demand situations (e.g., straight country road with no traffic at daytime) may require less attention because the driver can usually predict what will happen in the next few seconds while the driver is attending elsewhere. Conversely, high demand (e.g., multi-lane winding road with erratic traffic) situations may require more attention because during any time attention is diverted away, there is a high probability that a novel response may be required.  It is likely that most intuitively drivers take the driving-task demand into account when deciding whether or not to engage in a non-driving task.  Although this assumption is likely to be valid in a general sense, a counter argument is that problems may also arise when the situation appears to be relatively benign and drivers overestimate the predictability of the environment.  Driving environments that appear to be predictable may therefore leave drivers less prepared to respond when an unexpected threat does arise.

A safety system that mitigates the use of in-vehicle information and entertainment

[1] The distinction between driving and non-driving tasks may become blurred sometimes. For example, reading street signs and numbers is necessary for determining the correct course of driving, but may momentarily divert visual attention away from the forward road and degrade a driver's responses to unpredictable danger evolving in the driving path. In the SAVE-IT program, any off-road glances, including those for reading street signs, will be assessed in terms of visual distraction and the information about distraction will be fed into adaptive safety warning countermeasures and distraction mitigation sub-systems.

system (telematics) must balance both attention allocated to the driving task that will be assessed in Tasks 3 (Performance), 5 (Cognitive Distraction), and 7 (Visual Distraction) and attention demanded by the environment that will be assessed in Task 2 (Driving Task Demand). The goal of the distraction mitigation system should be to keep the level of attention allocated to the driving task above the attentional requirements demanded by the current driving environment. For example, as shown in Figure ii, “routine” driving may suffice during low or moderate driving task demand, slightly distracted driving may be adequate during low driving task demand, but high driving task demand requires attentive driving.

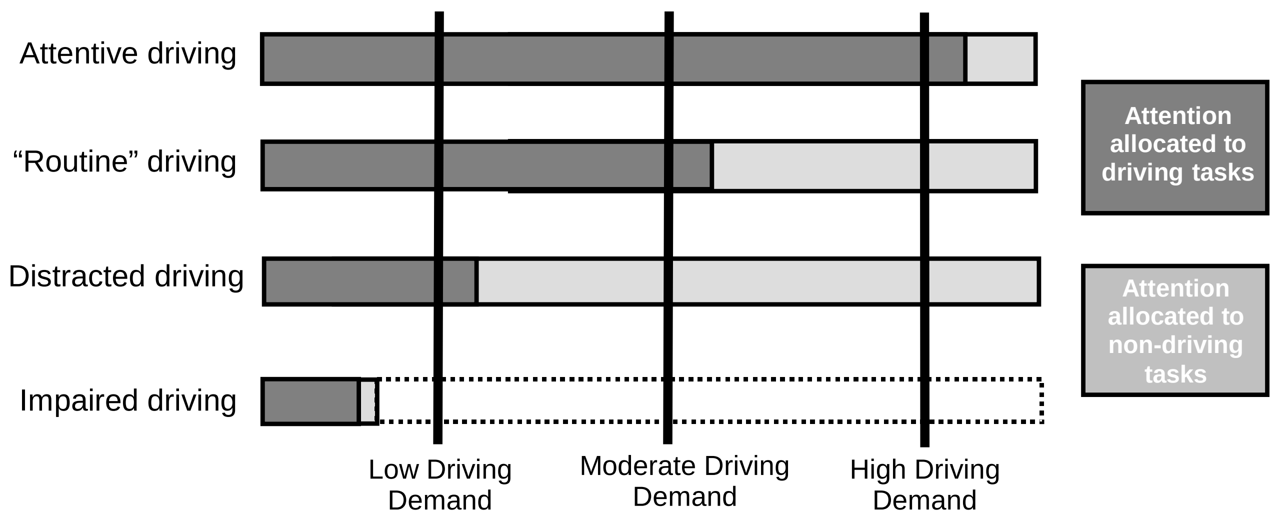


Figure ii. Attention allocation to driving and non-driving tasks

It is important to note that the SAVE-IT system addresses both high-demand and low-demand situations. With respect to the first prong (Safety Warning Countermeasures sub-system), the safety warning systems (e.g., the FCW system) will always be active, regardless of the demand. Sensors will always be assessing the driving environment and driver state. If traffic threats are detected, warnings will be issued that are commensurate with the real time attentiveness of the driver, even under low-demand situations. With respect to the second prong (Distraction Mitigation sub-system), driver state including driver distraction and intent will be continuously assessed under all circumstances. Warnings may be issued and telematics functions may be screened out under both high-demand and low-demand situations, although the threshold for distraction mitigation may be different for these situations.

It should be pointed out that drivers tend to adapt their driving, including distraction behavior and maintenance of speed and headway, based on driving (e.g., traffic and weather) and non-driving conditions (e.g., availability of telematics services), either consciously or unconsciously. For example, drivers may shed non-driving tasks (e.g., ending a cell phone conversation) when driving under unfavorable traffic and weather conditions. It is critical to understand this "driver adaptation" phenomenon. In principle, the "system adaptation" in the SAVE-IT program (i.e., adaptive safety warning countermeasures and adaptive distraction mitigation sub-systems) should be carefully implemented to ensure a fit between the two types of adaptation: "system adaptation" and "driver adaptation". One potential problem in a system that is inappropriately implemented is that the system and the driver may be reacting to each other in an unstable manner. If the system adaptation is on a shorter time scale than the driver adaptation, the driver may become confused and frustrated. Therefore, it is important to take the time scale into account. System adaptation should fit the driver's mental model in order to ensure driver understandability and user acceptance. Because of individual difference, it may also be important to tailor the system to individual drivers in order to maximize driver understandability and user acceptance. Due to resource constraints, however, a nominal driver model will be adopted in the initial SAVE-IT system. Driver profiling, machine learning of driver behavior, individual difference-based system tailoring may be investigated in future research programs.

## Communication and Commonalities Among Tasks and Sites

In the SAVE-IT program, a "divide-and-conquer" approach has been taken. The program is first divided into different tasks so that a particular research question can be studied in a particular task. The research findings from the various tasks are then brought together to enable us to develop and evaluate integrated systems. Therefore, a sensible balance of commonality and diversity is crucial to the program success. Diversity is reflected by the fact that every task is designed to address a unique question to achieve a particular objective. As a matter of fact, no tasks are redundant or unnecessary. Diversity is clearly demonstrated in the respective task reports. Also documented in the task reports is the creativity of different task owners in attacking different research problems.

Task commonality is very important to the integration of the research results from the various tasks into a coherent system and is reflected in terms of the common methods across the various tasks. Because of the large number of tasks (a total of 15 tasks depicted in Figure i) and the participation of multiple sites (Delphi Electronics & Safety, University of Iowa, UMTRI, Ford Motor Company, and General Motors), close coordination and commonality among the tasks and sites are key to program success. Coordination mechanisms, task and site commonalities have been built into the program and are reinforced with the bi-weekly teleconference meetings and regular email and telephone communications. It should be pointed out that little time was wasted in meetings. Indeed, some bi-weekly meetings were brief when decisions can be made quickly, or canceled when issues can be resolved before the meetings. The level of coordination and commonality among multiple sites and tasks is un-precedented and has greatly contributed to program success. A selection of commonalities is described below.

<u>Commonalities Among Driving Simulators and Eye Tracking Systems In Phase I</u>
Although the Phase I tasks are performed at three sites (Delphi Electronics & Safety, University of Iowa, and UMTRI), the same driving simulator software, Drive Safety™ (formerly called GlobalSim™) from Drive Safety Inc., and the same eye tracking system,

FaceLab™ from Seeing Machines, Inc. are used in Phase I tasks at all sites. The performance variables (e.g., steering angle, lane position, headway) and eye gaze measures (e.g., gaze coordinate) are defined in the same manner across tasks.

Common Dependent Variables An important activity of the driving task is tactical maneuvering such as speed and lane choice, navigation, and hazard monitoring. A key component of tactical maneuvering is responding to unpredictable and probabilistic events (e.g., lead vehicle braking, vehicles cutting in front) in a timely fashion. Timely responses are critical for collision avoidance. If a driver is distracted, attention is diverted from tactical maneuvering and vehicle control, and consequently, reaction time (RT) to probabilistic events increases. Because of the tight coupling between reaction time and attention allocation, RT is a useful metric for operationally defining the concept of driver distraction. Furthermore, brake RT can be readily measured in a driving simulator and is widely used as input to algorithms, such as the forward collision warning algorithm (Task 9: Safety Warning Countermeasures). In other words, RT is directly related to driver safety. Because of these reasons, RT to probabilistic events is chosen as a primary, "ground-truth" dependent variable in Tasks 2 (Driving Task Demand), 5 (Cognitive Distraction), 6 (Telematics Demand), 7 (Visual Distraction), and 9 (Safety Warning Countermeasures).

Because RT may not account for all of the variance in driver behavior, other measures such as steering entropy (Boer, 2001), headway, lane position and variance (e.g., standard deviation of lane position or SDLP), lane departures, and eye glance behavior (e.g., glance duration and frequency) are also be considered. Together these measures will provide a comprehensive picture about driver distraction, demand, and workload.

Common Driving Scenarios For the tasks that measure the brake RT, the "lead vehicle following" scenario is used. Because human factors and psychological research has indicated that RT may be influenced by many factors (e.g., headway), care has been taken to ensure a certain level of uniformity across different tasks. For instance, a common lead vehicle (a white passenger car) was used. The lead vehicle may brake infrequently (no more than 1 braking per minute) and at an unpredictable moment. The vehicle braking was non-imminent in all experiments (e.g., a low value of deceleration), except in Task 9 (Safety Warning Countermeasures) that requires an imminent braking. In addition, the lead vehicle speed and the time headway between the lead vehicle and the host vehicle are commonized across tasks to a large extent.

Subject Demographics It has been shown in the past that driver ages influence driving performance, user acceptance, and driver understandability. Because the age effect is not the focus of the SAVE-IT program, it is not possible to include all driver ages in every task with the budgetary and resource constraints. Rather than using different subject ages in different tasks, however, driver ages are commonized across tasks. Three age groups are defined: younger group (18-25 years old), middle group (35-55 years old), and older group (65-75 years old). Because not all age groups can be used in all tasks, one age group (the middle group) is chosen as the common age group that is used in every task. One reason for this choice is that drivers of 35-55 years old are the likely initial buyers and users of vehicles with advanced technologies such as the SAVE-IT systems. Although the age effect is not the focus of the program, it is examined in some tasks. In those tasks, multiple age groups were used.

The number of subjects per condition per task is based on the particular experimental design and condition, the effect size shown in the literature, and resource constraints. In order to ensure a reasonable level of uniformity across tasks and confidence in the research results, a minimum of eight subjects is used for each and every condition. The typical number of subjects is considerably larger than the minimum, frequently between 10-20.

Other Commonalities In addition to the commonalities across all tasks and all sites, there are additional common features between two or three tasks. For example, the simulator roadway environment and scripting events (e.g., the TCL scripts used in the driving simulator for the headway control and braking event onset) may be shared between experiments, the same distraction (non-driving) tasks may be used in different experiments, and the same research methods and models (e.g., Hidden Markov Model) may be deployed in various tasks. These commonalities afford the consistency among the tasks that is needed to develop and demonstrate a coherent SAVE-IT system.

## The Content and Structure of the Report

This document reports on the crash database analysis results from Task 2a of the SAVE-IT project. This document presents the methods utilized for analysis of Michigan Highway Safety Information System data to produce crash rate look-up tables for use by the SAVE-IT system to estimate driving task demand. The report concludes with a discussion of crash rates as a surrogate measure of demand, the need for validation, and further research.

## 2.1 INTRODUCTION

The safe operation of a motor vehicle requires a driver to focus a portion of his or her attentional capacity on the task of driving. As depicted in Figure ii, this project assumes that the level of attention required for safe driving is correlated with the level of demand imposed on the driver by the driving environment, called the driving task demand. Figure ii shows the relationships between attentional capacity, the portion of that capacity devoted to driving, and driving task demand. During conditions in which the attentional capacity is not impaired, differing proportions of attention can be devoted to the driving task, depending on the moment-to-moment distractions both inside and outside the vehicle (see Eby & Kostyniuk, 2003a, for a review of these distractions). The amount of attention required for safe driving is a function of the driving task demand. As demand increases, a greater proportion of attention is required for safe driving. If too little attention is paid to driving in relation to the demand, such as "routine" driving during high driving task demand (Figure ii), the driver is at increased risk for a distraction-related crash.

As discussed in the literature review for this task (Eby & Kostyniuk, 2003b), highway design and standardization efforts have undoubtedly lowered the driving task demands by reducing road complexity and increasing its predictability (American Association of State Highway and Transportation Officials, 2001; Federal Highway Administration, FHWA, 2000). Some road segments, however, require a greater level of attention from drivers than others. The driving task demand of a particular road segment may change with variations in traffic volumes, density, mix of vehicle types, and presence of construction or repair activities. Driving the same road segment in rain, in the dark, or under other inclement conditions may also require increased driving task demand.

Previous researchers have hypothesized that crash rates by roadway and environmental features may be indicative of the demand placed on the driver by those roadway and environmental features (see, e.g., Versace, 1960). That is, crash rates may be indicative of the volatility or unpredictability of driving under certain roadway and environmental conditions and are, therefore, likely to correlate highly with the amount of attention that is demanded by the environment for certain combinations of road, traffic, and environmental conditions.

The best surrogate measure of driving task demand based upon crash rates would be to have a general model where road and environmental variables could be plugged in, and a predicted crash rate obtained, as is the goal for the crash prediction models developed for two-lane rural road segments and intersections by Harwood et al. (2000). Their models were developed as part of a large multi-year FHWA Interactive Highway Design Model (IHDM) effort which, when completed, will provide methods and models to estimate the probability of crashes on many types of roads and intersections. Given the limited resources of this task, this effort cannot extend the Harwood et al. (2000) work. It can, however, produce first-order estimates based on crash rates obtained from tabulations of available data. These crash rates can then be organized into "look-up" tables based upon several important variables. In the future, the look-up table could be replaced by the crash prediction models from IHDM as they are released.

This document has two purposes. The first is to report the methods, procedures, and results for the development of crash-rate look-up tables to be utilized by SAVE-IT as a surrogate measuring driving task demand. The use of crash probabilities as a surrogate measure of driving task demand is a reasonable first-pass method for establishing a "proof-of-concept" in the early phases of the development of the SAVE-IT system. The second purpose is to provide conclusions on the use of crash probabilities as an indicator of driving task demand as well as discuss validation and other future work.

# 2.2. METHODS

## 2.2.1. Crash Database

As discussed in an earlier document (Eby & Kostyniuk, 2003b), The National Accident Sampling System (NASS) Highway Safety Information System (HSIS) Michigan database was selected for this task for two reasons: (1) HSIS contains the most detailed crash information regarding the roadway and environment; and (2) Michigan was selected because later testing of the SAVE-IT technologies will take place in that state. The Michigan HSIS databases covers about 10,000 miles of state trunkline roadway and contains a crash data file and separate files with geometric and operational variables for road segments, intersections, and interchanges. The most recent Michigan HSIS data systems are from 1996 and 1997, and have information on about 36,000 road segments, 28,000 intersections, and 750 interchanges. HSIS data were obtained from the FHWA, after a process of application, review, and approval. Because the objective was to obtain crash rates for specific types of locations, information was requested on road segments, intersections, and interchanges.

## 2.2.2. Data Analysis

### 2.2.2.1. Road Segments

Information on geometric and operational characteristics of road segments is contained the Michigan Roadlog file. The segments are homogenous in geometric and operational characteristics and vary in length. Most segments are quite short. Section length is a variable in the file, as are beginning and ending mileages along the route. Data files from the Michigan HSIS were created for this study by FHWA HSIS per our request. These data included a road segment file which consisted of information on road segments (functional class, road classification, road type, rural/urban environment, curvature, grade, terrain, passing, number of lanes, lane width, left and right shoulder type and width, speed limit, average annual daily travel or AADT, and segment length). Thus we obtained crash counts for the following categories for each segment for years 1996 and 1997:

- all crashes
- by peak and off peak conditions
- by light conditions
    - daylight
    - dawn
    - dusk
    - night - no street lights
    - night street light
- peak and light conditions
    - peak daylight
    - peak dawn
    - peak dusk

peak - night no street lights
peak - night street lights
off peak daylight
off peak dawn
off peak dusk
off peak - night no street lights
off peak - night street lights

Crash counts were also obtained by weather conditions, and by peak/light/weather, but we were unable to calculate exposure by weather, so conditions that included weather or weather combinations had to be dropped from these analyses.

Segmentation analysis (Sonquist et al., 1973) using SEARCH software (Morgan, Solenberger, Van Eck, & Nagara, 2003)[1] was used to divide the road segments into mutually exclusive and collectively exhaustive subgroups. Segmentation analysis was selected over modeling efforts because it allowed us to explore the data set and search it for structure without restrictive assumptions of linearity or additivity of effects, and resources needed for modeling were beyond those allocated for the effort. SEARCH was selected from among various segmentation algorithms because it allowed for dependent variables to be either continuous or categorical, and for predictor variables to be ordinally or nominally scaled.

SEARCH divided the sample through a series of binary splits into a mutually exclusive series of subgroups. The splits are chosen by the algorithm so that at each step in the procedure, the split into the two new subgroups accounted for more of the variance than a split into any other pair of subgroups. The SEARCH process stopped when additional split-criteria based on minimum group size, maximum number of splits, or minimum reduction in explained variance relative to the original total was reached.

It should be noted that the resulting groups identified by the SEARCH algorithm are unique to this particular data set; that is, if a data set from another year was used, the final groupings might be different. Therefore, it is important to examine the SEARCH results in light of what is known about the effects of various road features on crash experience. SEARCH results are intended to help a researcher examine a data set, and provide guidance for further research.

The dependent variable selected for the SEARCH segmentation was the overall crash rate (crashes per mile per year) and predictor variables were the descriptive features of the road segment. Several different sets of independent variables were tested. Whenever traffic volume (AADT) was included in the analysis, it dominated the rates, indicating that traffic crash frequency is highly related to traffic volume. This variable, therefore, was removed from the analyses. Removal of AADT from the set of predictor variables allowed other characteristics of the road segment to appear in the binary

[1] The SEARCH software is available free of charge from the University of Michigan Institute for Social Research (ISR) and can be downloaded at: http://www.isr.umich.edu/src/smp/search.

splits. Effects of volume still appear in the analysis because many of these variables are correlated with traffic volume. For example, high volumes are found on roads with the functional classification of principal arterials, and low volumes are usually found on local collector roads. Furthermore, wide lanes and wide shoulders are more likely to be found on roads that carry high volumes of traffic than on roads that carry low volumes of traffic. A further exploration of traffic volume and crash rates can be found in the Appendix, where segmentation analyses were conducted on crashes/1,000 vehicles AADT and by crashes/mile/1,000 vehicles AADT.

The variables in the final SEARCH model included:

*Dependent Variable*

crashes per mile per year

*Predictive Variables*

number of base lanes
lane width
left shoulder width
right shoulder width
speed limit
passing
degree of curve
road class
functional class
rural/urban environment

It should be noted that the because approximately 78 percent of the HSIS road mileage is rural, there are many more rural road segments than urban road segments in the Michigan HSIS file. This is reflected in the terminal SEARCH subgroups, with more segmentation of rural-type roads than of urban roads.

Because SEARCH used only cases with no missing values for any of the specified predictive variables, only 73 percent of the road segments in the data file were used in the classification. This affected the final grouping of road segments for the calculation of the table of crash rates in two ways. First, we examined the terminal groups, to check if any type of roadway was missing. We found that the functional road classification category of “rural major arterials - Interstate” was not included in the cases used in the SEARCH segmentation because of consistent missing values for some of the variables. Examination of these segments found 95 percent of them to be freeway segments, and 78 percent of them to have four lanes. Because this is an important category of roadway, it was added to the final subgroups. Second, final crash rates would be calculated using all available segments for that category, not just the ones used in the segmentation.

Crash rates by the peak and light conditions were calculated for each road segment subgroup. These rates were based on the crash counts for the various conditions and the exposure to these conditions using the following methods. Peak periods of traffic were defined as 6-9 am and 3-6 pm for Monday through Friday. Offpeak was all other times. The number of hours for each of the light conditions (daylight, dawn, dusk, and dark) were estimated for Mount Pleasant, Michigan (W084 46, N43 36), a central location in Michigan using tables of sunrise, sunset, and nautical twilight from the US Naval Observatory (http://aa.usno.navy.mil/). Nautical twilight was defined as beginning in the morning and ending in the evening, when the center of the sun was geometrically 12 deg below the horizon. At the beginning or end of nautical twilight, under good atmospheric conditions and in the absence of other illumination, general outlines of ground objects may be distinguishable and the horizon is indistinct. Sunrise and sunset were defined to occur when the geometric zenith distance of the center of the sun was 90.8333 deg. That is, the center of the sun is geometrically 50 arcmin below the horizontal plane. Daylight time was computed as the time between sunrise and sunset. Dawn time was computed as the time between the beginning of nautical twilight and sunrise. Dusk time was computed as the time between sunset and the end of nautical twilight. Dark time was computed as the time between the end and beginning of nautical twilight. Daylight Savings Time was included in the determination of hours of time by light and peak period conditions. Crash rate per mile for lighting conditions and for traffic conditions were normalized by exposure to that condition. For example, to obtain the normalized dawn crash rate for a particular segment, the number of dawn crashes on that segment in one year was divided by the proportion of dawn hours in one year. This normalization gives a comparable rate across the light and peak/off peak conditions for this segment.

### 2.2.2.2. Intersections

The intersection data file from HSIS Michigan was created for this study by FHWA HSIS per our request. Intersection crashes are those that occurred within 250 feet of an intersection on any approach. The intersection crash file included the following variables:

- intersection type
- number of legs
- if intersection is with trunkline or nontrunkline road
- identifying information (milepost, control section)
- signal control type at the intersection - (no signal, fixed time signal, semi-actuated, fully actuated, flasher)
- Presence of auxiliary (turn) lanes at intersection
- Traffic volume (on trunkline)

The presence of left turn phase on trunkline and crossroad approaches and departures was requested and received. This variable, however, was coded as missing for most cases. We omitted this variable from the analyses.

As with the road-segment crash file, crash counts were obtained for each intersection for years 1996 and 1997 for:

- all crashes
- by peak and off peak conditions
- by light conditions
    - daylight
    - dawn
    - dusk
    - night - no street lights
    - night street lights
- peak and light conditions
    - peak daylight
    - peak dawn
    - peak dusk
    - peak - night no street lights
    - peak - night street lights
    - off peak daylight
    - off peak dawn
    - off peak dusk
    - off peak - night no street lights
    - off peak - night street lights

Crash counts were also obtained by weather conditions, and by peak x light x weather, but we were unable to calculate exposure by weather, so conditions that included weather or weather combinations could not be used.

Segmentation analysis using SEARCH software was used to divide the intersections into mutually exclusive and collectively exhaustive subgroups. The dependent variable selected for the SEARCH segmentation was the overall crash rate (crashes per year) and predictor variables were the descriptive features of the intersections. Several different sets of independent variables were tested. Whenever traffic volume (AADT) was included in the analysis, it dominated, indicating that traffic crashes at intersections are highly correlated with traffic volume. As with the road segments, we removed AADT from the set of predictor variables, to allow other characteristics of the intersection to appear in the binary splits.

The variables in the final SEARCH model for intersections included:

*dependent variable*
    crashes per year

*predictive variables*
    intersection type
    signal type
    number of legs
    presence of auxiliary (turn) lanes

There were 27,956 intersections in the analysis file. All intersections in the file were used in the SEARCH analysis and in the calculation of the rates by the peak and light conditions. Peak and light conditions were defined and calculated in the same way as the analyses for the road segments.

After the SEARCH program divided the intersection file into groups, the crash rates (crashes per year) were adjusted to match the segment crash rates (crashes per year per mile). Because intersection crashes are defined as occurring within 250 ft of an intersection, the distance covered by the intersection is 250 ft multiplied by the number of legs in the intersection. Intersection rates were adjusted for distance using the following formula: (250 ft ÷ 5280 ft/mile) x the number of legs in the intersection. This resulted in intersection crash rates per year and mile. These rates are reported in this document.

### 2.2.2.3. Freeway Interchange Elements

Information about freeway interchanges was obtained from the Michigan HSIS interchange file. The interchange file is different from the segment and intersection files in that crash counts (total and by several categories) are already included in the file. The crash counts are for a three-year period and are given for elements (e.g., on ramps, off ramps, etc.) at the interchange. The 1996 interchange file, the most current data file available, was used in the analysis and included crash counts for the years 1994-1996. The file contained information on over 6,000 elements from approximately 750 intersections.

Because of the limited amount of information available for interchanges, segmentation analysis was inappropriate to use. Instead, the interchange elements were classified by type of interchange, whether the interchange was in a rural or urban area, and by the function of the element itself.

The classifications were:

- <u>Rural/urban</u>: This classification was defined by the activity density (ACT_DEN) variable in HSIS.
- <u>Interchange type</u> (see Figure 2a.1 for examples of some of the intersection types):
    - o *Diamond* (n = 216; 28.3% of intersections): a category that collapsed intersections across the following HSIS definitions: modified diamond, partial diamond, split diamond, diamond plus one loop;
    - o *Tight Diamond* (n = 132; 17.3% of intersections): a category that collapsed intersections across the following HSIS definitions: tight diamond, modified tight diamond, partial tight diamond;
    - o *Urban Diamond* (n = 50; 6.6% of intersections): included only intersection defined as “urban diamond” by HSIS;
    - o *Partial Cloverleaf (Parclo) and Cloverleaf* (n = 154; 20.0% of

intersections): a category that collapsed intersections across the following HSIS definitions: parclo a, parclo b, parclo a 4 quad, parclo b 4 quad, parclo ab, parclo ab 4 quad, cloverleaf, cloverleaf with collector distributor roads, cloverleaf minus one loop;
  - *Trumpet* (n = 21; 2.8% of intersections): a category that collapsed intersections across the following HSIS definitions: trumpet a, trumpet b;
  - *Directional* (n = 74; 9.7% of intersections): a category that collapsed intersections across the following HSIS definitions: full directional, partial directional, directional Y, general directional, partial directional Y, directional with loops;
  - *Other* (n = 116; 15.2% of intersections): a category that collapsed intersections across the following HSIS definitions: general, sri-a, sri-b, other.
- Element. The four elements used in analysis were:
  - *Mainline* (one-way freeway segment carrying through traffic at an interchange), a category that collapsed across the following HSIS definitions: NB mainline, SB mainline, EB mainline, WB mainline, NE mainline, SW mainline, NW mainline, SE mainline
  - *On-ramp* (one-way roadway directly connecting the local road network with the freeway system, either the freeway mainline of the freeway collector roadway, including the roadways connecting freeway rest areas and weigh stations with the freeway), a category that collapsed across the following HSIS definitions: spread, tight, or loop on-ramp from cross road to freeway; on ramp from service road, rest area, or weigh station to freeway; on-ramp from cross road or service road to collector distributor; loop ramp from cross road to collector distributor;
  - *Off-ramp* (one-way roadways from the freeway system to the local road network, including off ramps from the mainline freeway to the local road, if there is no collector distributor road, the ramp from the collector distributor road to the local network, if collector distributor is present, and roadways from freeway to rest areas and weight stations), a category that collapsed across the following HSIS interchange elements definitions: spread, tight, or loop off-ramp from freeway to cross road; off ramp from freeway to service road, rest area, or weigh station; off ramp from collector distributor to cross road or service road; loop ramp from collector distributor to cross road;
  - *Freeway Element to Freeway Element* (interchange elements connecting freeway elements with other freeway elements, including connections between collector distributor with the freeway and ramps and turning roadways connecting mainlines of freeways associated with collection and distribution of traffic at interchanges), a category that collapsed across the following HSIS interchange elements definitions: collector distributor; ramp from collector distributor to collector distributor; directional loop ramp; directional ramp; turning roadway; loop ramp from collector distributor to collector distributor; off ramp from freeway to collector distributor; on ramp from collector distributor to freeway; loop ramp from collector distributor to freeway; loop ramp from freeway to collector distributor.

There were 24 rural and 28 urban categories of freeway interchange elements. The average number of crashes for each category of freeway element was calculated as follows:

- Data used were total crashes and dark crashes. Because each category of crash was a 3-year total, each crash type was divided by three to get a 1-year value. The number of daylight crashes was calculated by subtracting dark crashes from all crashes.
- Exposure by light conditions was estimated by assuming that daylight conditions were the daylight hours + ½ of dawn and ½ of dusk hours. Dark conditions were assumed to be the time from sunset to sunrise + ½ of dawn and ½ of dusk hours. Dawn and dusk were defined as described previously. Using these calculations the proportion of daylight hours in a year in a central location in Michigan was .5568 and the proportion of dark hours was .4432.

In order to be consistent with the segment and intersection crash rates that are expressed in crashes per year per mile, we needed to convert the interchange crash rates so that they took into account length. Unfortunately, the data file did not contain information about the lengths of the freeway elements. We first attempted to estimate lengths using the current MDOT Design Guide for Freeway Entrance and Exit Ramps and Collector Distributor Roads (Michigan Department of Transportation, 1998). This guide, however, contained the current standards, and most of the freeway interchanges were built to older standards. Instead, we conducted a limited field study in which we measured various freeway interchange elements on several different freeways in the Southeast Michigan area. Average values were calculated and the following averages were used to estimate crash rates per mile of interchange element: all on and off ramps (except rest area) in rural areas (0.3 miles); rest area on and off ramps (0.2 miles); all tight on and off ramps in rural areas (0.2 miles); all on and off ramps in urban areas (0.2 miles); all mainline elements for rural and urban areas (0.5 miles); collector and distributor elements (0.5 miles); and freeway to freeway elements, turning roads, freeway to collector-distributor and collector distributor to freeways (0.5 miles). This method for determining freeway interchange element length was crude, but judged to be adequate for determining a “proof-of-concept” for SAVE-IT. In actual use, it would be better to measure and use the actual lengths of each interchange element

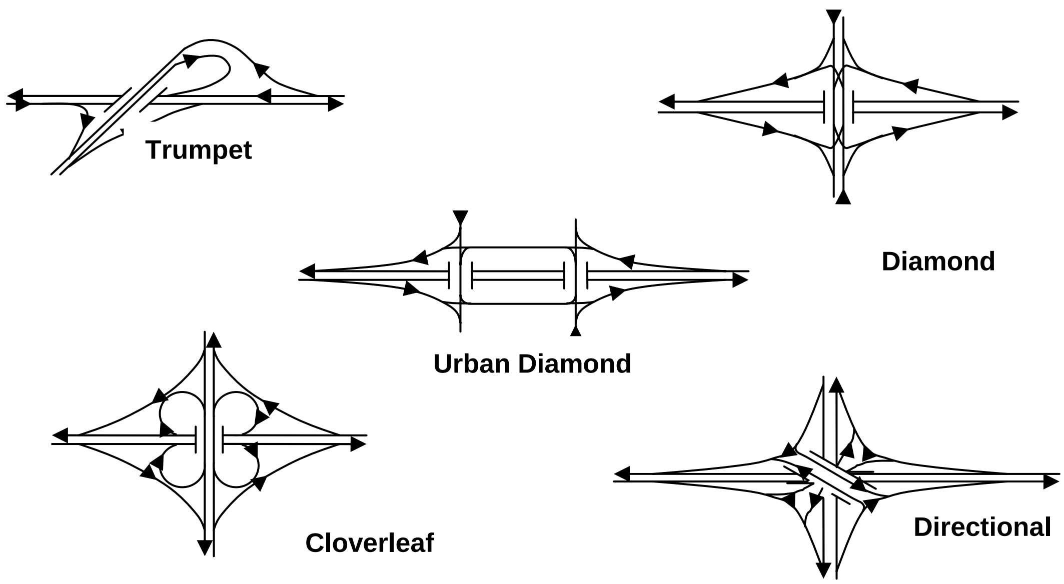


**Figure 2a.1. Example interchange types used in the analysis of Michigan HSIS Freeway Interchange Elements.**

## 2.3 RESULTS

The purpose of the crash data analysis portion of this task was to develop look-up tables of crash probabilities, so that at any given moment while a SAVE-IT-equipped vehicle is moving, the driving task demand can be estimated by moving a “pointer” through the look-up tables based upon the data about the roadway and environment that can be sensed by SAVE-IT. As discussed previously, the crash data is organized into three types of roadway categories: segments, intersections, and freeway interchange elements. Collectively these categories account for all general types of roadways. Results are presented as a function of these three categories.

### 2.3.1. Segments

Figure 2a.2 shows the top-level structure of the look-up tables for segments. The boxes shown in this figure were determined by the segmentation analysis, except for box 20 (shown with dashed lines). We added this box because rural freeways are an important road segment functional classification that was dropped by the segmentation analysis because the majority of the rural freeway crashes contained missing data.

Within each box, the variable values on which the segmentation analysis split was based are indicated (uniquely defining the box); “R” equals the crash rate (number of crashes/year/mile); and “N” equals the number of segments on which the rate for that box was calculated. Depending upon the information available to the system at the given moment, the look-up table pointer would move down a branch of the top-level structure until it reaches a terminal box (shown with thick outlines) or a box in which the SAVE-IT system does not have the information for the pointer to move to the next level. Once this occurs, the look-up table pointer would move to the look-up table associated with the final box (Tables 2a.1 – 2a.20). These tables contain crash rates based upon the terminal box variables; environmental lighting conditions; peak/non peak; and the various combinations of lighting and peak/non peak values. Again, depending upon the information available to the SAVE-IT system, the pointer would point at the crash rate based upon the highest level of detail available.

As conditions change, or the ability to sense the variables changes, the pointer would move through the tables always pointing at the crash rate that is based upon the greatest amount of information available to SAVE-IT. High crash rates would indicate high driving task demand whereas low crash rates would indicate low driving task demand. Converting these rates into an appropriate level of demand will be conducted in future research.

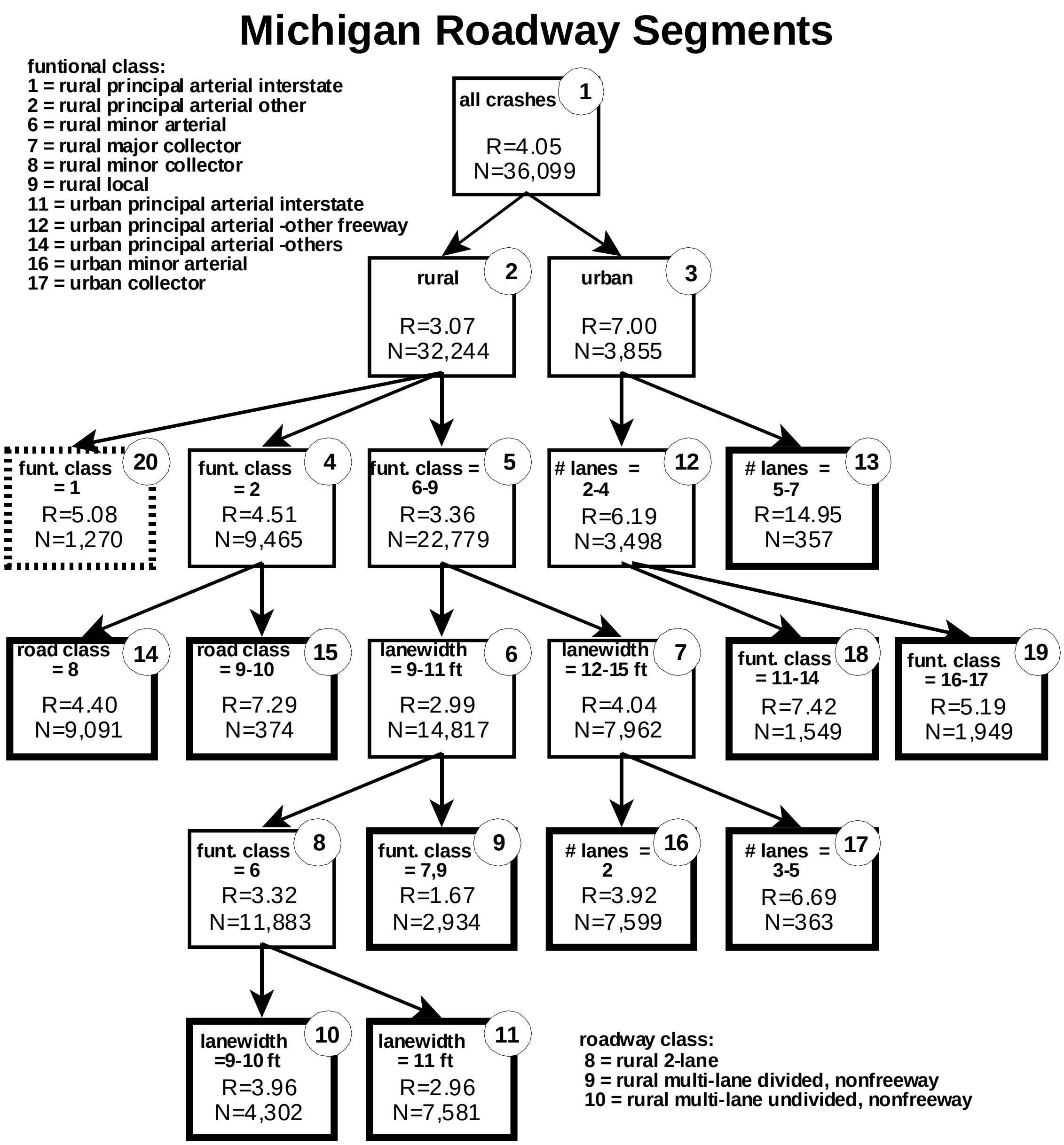


**Figure 2a.2. Top level crash-rate look-up table structure for roadway segments in Michigan.**

| Table 2a.1: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Segments by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (4.8) | Dusk (4.1) | Daylight (5.6) | Dark: No Streetlight (4.2) | Dark: Streetlight (1.2) |
| Peak (8.2) | 5.4 | 8.4 | 6.3 | 25.8 | 6.9 |
| Off Peak (4.9) | 1.5 | 5.6 | 4.3 | 3.5 | 0.9 |

| Table 2a.2: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Rural Segments by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (4.3) | Dusk (3.2) | Daylight (3.0) | Dark: No Streetlight (4.5) | Dark: Streetlight (0.3) |
| Peak (5.0) | 4.9 | 5.7 | 3.3 | 27.6 | 2.2 |
| Off Peak (3.6) | 1.5 | 4.8 | 2.5 | 3.8 | 0.3 |

| Table 2a.3: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Urban Segments by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (6.2) | Dusk (7.0) | Daylight (14.0) | Dark: No Streetlight (3.2) | Dark: Streetlight (4.1) |
| Peak (19.0) | 7.0 | 17.2 | 16.4 | 19.6 | 22.3 |
| Off Peak (9.1) | 1.7 | 8.2 | 10.4 | 2.5 | 3.2 |

| Table 2a.4: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Rural Non-Freeway Principal Arterial Segments by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (4.5) | Dusk (3.9) | Daylight (3.9) | Dark: No Streetlight (5.3) | Dark: Streetlight (0.4) |
| Peak (6.0) | 4.8 | 6.8 | 4.2 | 33.8 | 2.7 |
| Off Peak (4.4) | 1.7 | 5.8 | 3.2 | 4.5 | 0.4 |

| Table 2a.5: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Rural Non-Principal Segments by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (4.3) | Dusk (2.9) | Daylight (2.5) | Dark: No Streetlight (4.1) | Dark: Streetlight (0.3) |
| Peak (4.4) | 5.1 | 5.0 | 2.8 | 24.7 | 2.1 |
| Off Peak (3.1) | 1.3 | 4.3 | 2.0 | 3.5 | 0.2 |

| Table 2a.6: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Rural Non-Principal Segments with Lanes 9-11 Feet Wide by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (4.0) | Dusk (2.7) | Daylight (2.1) | Dark: No Streetlight (3.7) | Dark: Streetlight (0.2) |
| Peak (3.8) | 4.5 | 4.7 | 2.3 | 21.7 | 1.0 |
| Off Peak (2.8) | 1.3 | 4.1 | 1.7 | 3.1 | 0.2 |

| Table 2a.7: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Rural Non-Principal Segments with Lanes 12-15 Feet Wide by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (4.7) | Dusk (3.1) | Daylight (3.2) | Dark: No Streetlight (4.9) | Dark: Streetlight (0.4) |
| Peak (5.5) | 6.1 | 5.6 | 3.5 | 30.1 | 4.0 |
| Off Peak (3.8) | 1.3 | 4.8 | 2.6 | 4.1 | 0.3 |

| Table 2a.8: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Rural Minor Arterial Segments with Lanes 9-11 Feet Wide by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (4.3) | Dusk (3.0) | Daylight (2.3) | Dark: No Streetlight (4.1) | Dark: Streetlight (0.2) |
| Peak (4.2) | 4.9 | 5.5 | 2.5 | 23.9 | 1.2 |
| Off Peak (3.0) | 1.5 | 4.4 | 1.9 | 3.5 | 0.2 |

| Table 2a.9: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Rural Major Collectors and Local Road Segments with Lanes 9-11 Feet Wide by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (2.4) | Dusk (1.6) | Daylight (1.3) | Dark: No Streetlight (1.9) | Dark: Streetlight (0.1) |
| Peak (2.2) | 3.0 | 1.2 | 1.5 | 12.7 | 0.4 |
| Off Peak (1.6) | 0.7 | 2.7 | 1.1 | 1.6 | 0.1 |

| Table 2a.10: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Rural Minor Arterial Segments with Lanes 9-10 Feet Wide by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (5.4) | Dusk (3.2) | Daylight (2.6) | Dark: No Streetlight (5.0) | Dark: Streetlight (0.2) |
| Peak (5.0) | 6.0 | 6.3 | 3.1 | 26.2 | 1.1 |
| Off Peak (3.5) | 1.8 | 4.5 | 2.1 | 4.3 | 0.2 |

| Table 2a.11: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Rural Minor Arterial Segments with Lanes 11 Feet Wide by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (3.8) | Dusk (2.8) | Daylight (2.1) | Dark: No Streetlight (3.6) | Dark: Streetlight (0.2) |
| Peak (3.8) | 4.3 | 5.1 | 2.2 | 22.6 | 1.2 |
| Off Peak (2.7) | 1.3 | 4.3 | 1.8 | 3.0 | 0.2 |

| Table 2a.12: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Urban Segments With 2-4 Base Lanes by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (4.9) | Dusk (4.6) | Daylight (8.7) | Dark: No Streetlight (3.4) | Dark: Streetlight (2.1) |
| Peak (12.0) | 5.7 | 11.1 | 10.0 | 20.2 | 14.2 |
| Off Peak (6.1) | 1.2 | 5.6 | 6.6 | 2.8 | 1.7 |

| Table 2a.13: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Urban Segments With 5-7 Base Lanes by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (5.9) | Dusk (11.0) | Daylight (26.1) | Dark: No Streetlight (2.4) | Dark: Streetlight (7.4) |
| Peak (32.4) | 8.0 | 31.3 | 29.0 | 13.3 | 38.6 |
| Off Peak (15.2) | 1.0 | 10.7 | 20.0 | 1.9 | 5.5 |

| Table 2a.14: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Rural Principal Non-Freeway Arterial 2-Lane Segments by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (4.4) | Dusk (3.8) | Daylight (3.4) | Dark: No Streetlight (5.2) | Dark: Streetlight (0.3) |
| Peak (5.6) | 4.8 | 6.4 | 3.8 | 32.8 | 2.6 |
| Off Peak (4.1) | 1.7 | 6.0 | 2.8 | 4.4 | 0.3 |

| Table 2a.15: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Rural Non-Freeway Multilane Principal Arterial Segments by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (5.4) | Dusk (5.5) | Daylight (8.5) | Dark: No Streetlight (6.1) | Dark: Streetlight (1.7) |
| Peak (10.8) | 5.2 | 12.3 | 8.0 | 51.5 | 5.4 |
| Off Peak (7.4) | 2.5 | 5.7 | 7.3 | 4.9 | 1.5 |

| Table 2a.16: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Rural Non-Principal 2-Lane Segments with Lanes 12-15 Feet Wide by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (4.8) | Dusk (3.0) | Daylight (2.9) | Dark: No Streetlight (5.0) | Dark: Streetlight (0.3) |
| Peak (5.2) | 6.2 | 5.3 | 3.3 | 30.3 | 2.9 |
| Off Peak (3.7) | 1.3 | 4.5 | 2.3 | 4.2 | 0.2 |

| Table 2a.17: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Rural Non-Principal 3-5 Lane Segments with Lanes 12-15 Feet Wide by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (4.2) | Dusk (4.9) | Daylight (6.9) | Dark: No Streetlight (3.8) | Dark: Streetlight (1.8) |
| Peak (8.8) | 4.6 | 9.4 | 6.4 | 28.8 | 16.5 |
| Off Peak (5.7) | 1.7 | 7.7 | 5.9 | 3.0 | 1.4 |

| Table 2a.18: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Urban Principal Arterial Segments With 2-4 Base Lanes by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (5.2) | Dusk (4.9) | Daylight (9.8) | Dark: No Streetlight (3.4) | Dark: Streetlight (2.4) |
| Peak (13.6) | 5.5 | 11.9 | 11.5 | 20.5 | 16.5 |
| Off Peak (6.6) | 1.6 | 5.8 | 7.2 | 2.7 | 1.9 |

| Table 2a.19: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Urban Non-Principal Segments With 2-4 Base Lanes by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (4.2) | Dusk (4.0) | Daylight (6.5) | Dark: No Streetlight (3.5) | Dark: Streetlight (1.5) |
| Peak (8.7) | 6.4 | 8.8 | 6.8 | 19.6 | 8.5 |
| Off Peak (5.1) | 0.5 | 5.4 | 5.2 | 2.9 | 1.2 |

| Table 2a.20: Crashes Per Mile Per Year for all Michigan HSIS Crashes on Rural Principal Arterial Interstate Segments by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (3.9) | Dusk (5.3) | Daylight (6.8) | Dark: No Streetlight (5.4) | Dark: Streetlight (0.2) |
| Peak (5.9) | 3.7 | 7.5 | 5.5 | 26.2 | 0.2 |
| Off Peak (4.9) | 2.1 | 5.8 | 4.7 | 5.1 | 0.2 |

### 2.3.2. Intersections

Figure 2a.3 shows the top-level structure of the look-up tables for Michigan intersections. The boxes shown in this figure were determined by the segmentation analysis. Within each box, the variable values on which the segmentation analysis split was based are indicated (uniquely defining the box); “R” equals the crash rate (number of crashes/year/mile); and “N” equals the number of intersections on which the rate for that box was calculated. As with the segments, depending upon the information available to the system at the given moment, the look-up table pointer will move down a branch of the top-level structure until it reaches a terminal box (shown with thick outlines) or a box in which the SAVE-IT system does not have the information for the pointer to move to the next level. Once this occurs, the look-up table pointer would move to the look-up table associated with the final box (Tables 2a.21 – 2a.41). These tables contain crash rates based upon the box variables; environmental lighting conditions; peak/non peak; and the various combinations of lighting and peak/non peak values. Again, depending upon the information available to the SAVE-IT system, the pointer would point at the crash rate based upon the highest level of detail available to the SAVE-IT. As conditions change, or the ability to sense the variables is changes, the pointer would move through the tables always pointing at the crash rate that is based upon the greatest amount of information available to SAVE-IT.

## Michigan Intersections

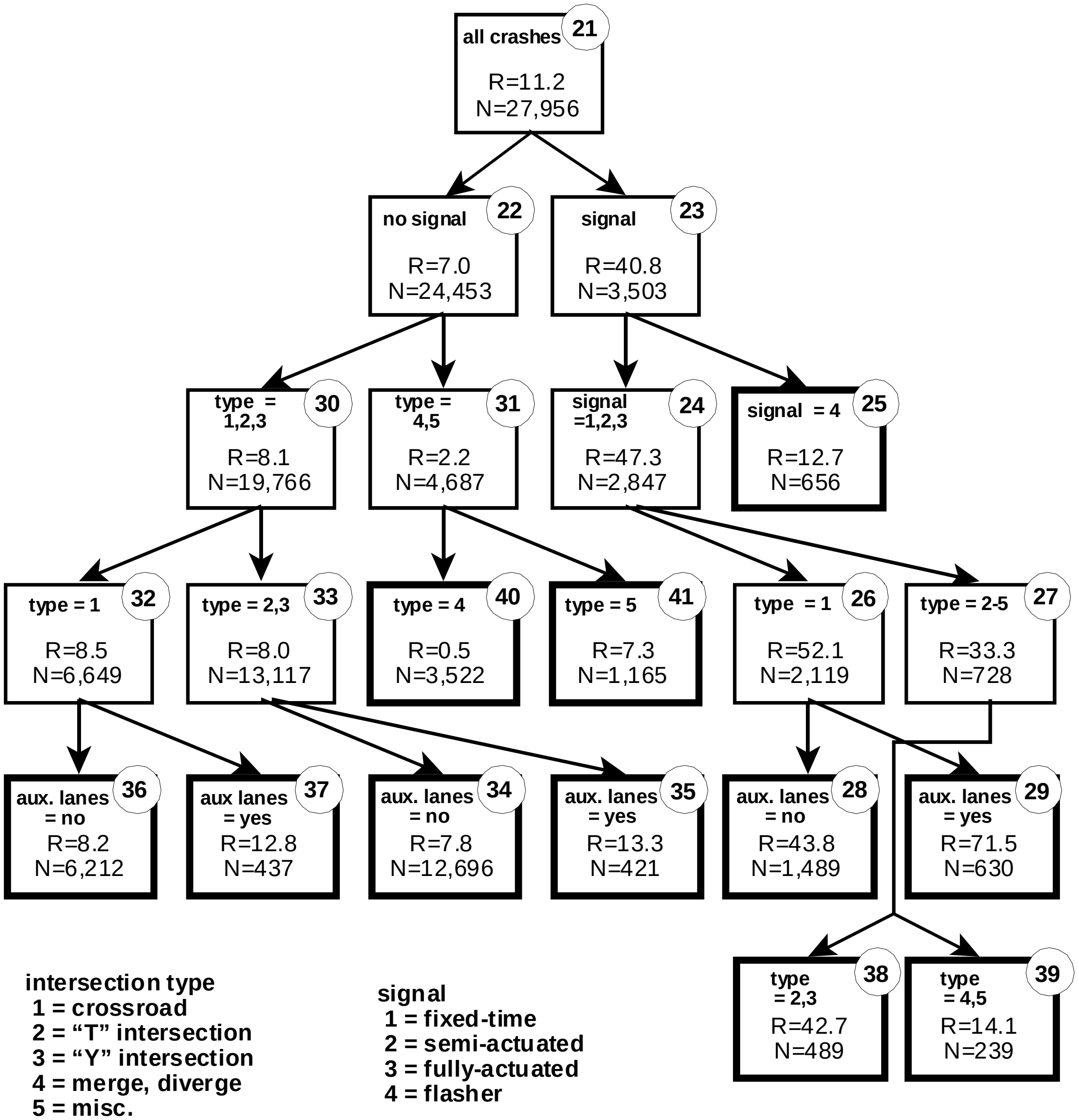


**Figure 2a.3. Top level crash-rate look-up table structure for intersections in Michigan.**

| Table 2a.21: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Intersections by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (4.5) | Dusk (8.3) | Daylight (20.9) | Dark: No Streetlight (1.6) | Dark: Streetlight (4.4) |
| Peak (19.8) | 6.5 | 19.5 | 21.4 | 12.5 | 28.5 |
| Off Peak (9.4) | 1.1 | 9.0 | 14.5 | 1.5 | 4.0 |

| Table 2a.22: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Intersections with No Signal by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (3.1) | Dusk (5.4) | Daylight (12.7) | Dark: No Streetlight (1.5) | Dark: Streetlight (2.5) |
| Peak (12.4) | 4.37 | 12.8 | 13.2 | 11.0 | 16.7 |
| Off Peak (5.8) | 0.8 | 5.9 | 8.8 | 1.3 | 2.3 |

| Table 2a.23: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Intersections With a Signal by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (14.5) | Dusk (28.2) | Daylight (78.4) | Dark: No Streetlight (2.6) | Dark: Streetlight (17.6) |
| Peak (71.5) | 21.1 | 66.6 | 78.4 | 22.7 | 110.4 |
| Off Peak (34.1) | 3.6 | 30.8 | 54.3 | 2.3 | 16.2 |

| Table 2a.24: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Intersections with Either a fixed, Semi-, or Fully-Actuated Signal by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (16.5) | Dusk (32.4) | Daylight (90.9) | Dark: No Streetlight (2.5) | Dark: Streetlight (20.8) |
| Peak (82.8) | 23.7 | 78.7 | 91.0 | 20.8 | 129.9 |
| Off Peak (39.5) | 4.1 | 35.3 | 62.9 | 2.3 | 19.2 |

| Table 2a.25: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Intersections With a Flasher by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (6.1) | Dusk (9.9) | Daylight (24.1) | Dark: No Streetlight (3.1) | Dark: Streetlight (3.6) |
| Peak (22.4) | 9.4 | 14.2 | 23.8 | 30.8 | 25.7 |
| Off Peak (10.6) | 1.2 | 10.8 | 16.7 | 2.6 | 3.2 |

| Table 2a.26: Crashes Per Mile Per Year for all Michigan HSIS Crashes at a Crossroad Intersections with Either a Fixed, Semi-, or Fully-Actuated Signal by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (18.4) | Dusk (35.7) | Daylight (100.57) | Dark: No Streetlight (2.5) | Dark: Streetlight (23.24) |
| Peak (90.15) | 25.9 | 84.3 | 99.2 | 17.2 | 144.6 |
| Off Peak (43.8) | 5.0 | 39.0 | 69.6 | 2.3 | 21.5 |

| Table 2a.27: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Non-Crossroad Intersections with Either a Fixed, Semi-, or Fully-Actuated Signal by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (10.9) | Dusk (22.8) | Daylight (62.9) | Dark: No Streetlight (2.5) | Dark: Streetlight (13.6) |
| Peak (61.4) | 17.6 | 62.3 | 67.0 | 31.2 | 87.0 |
| Off Peak (27.2) | 1.6 | 24.8 | 43.5 | 2.1 | 12.6 |

| Table 2a.28: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Non-Crossroad Intersections with Either a Fixed, Semi-, or Fully-Actuated Signal and No Auxiliary Lanes by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (14.6) | Dusk (29.4) | Daylight (85.5) | Dark: No Streetlight (1.5) | Dark: Streetlight (19.6) |
| Peak (76.0) | 19.8 | 70.7 | 84.3 | 8.7 | 121.2 |
| Off Peak (36.8) | 4.4 | 32.1 | 59.2 | 1.4 | 18.1 |

| Table 2a.29: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Non-Crossroad Intersections with Either a Fixed, Semi-, or Fully-Actuated Signal and Auxiliary Lanes by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (27.2) | Dusk (50.6) | Daylight (136.2) | Dark: No Streetlight (5.1) | Dark: Streetlight (31.9) |
| Peak (123.5) | 40.1 | 116.3 | 134.3 | 37.4 | 200.0 |
| Off Peak (60.2) | 6.3 | 55.2 | 94.3 | 4.6 | 29.4 |

| Table 2a.30: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Crossroad, "T", or "Y" Intersections with No Signal by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (3.6) | Dusk (6.3) | Daylight (14.8) | Dark: No Streetlight (1.8) | Dark: Streetlight (2.8) |
| Peak (14.4) | 5.1 | 14.7 | 15.3 | 13.2 | 19.2 |
| Off Peak (6.8) | 0.9 | 6.9 | 10.2 | 1.6 | 2.6 |

| Table 2a.31: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Merge/Diverge or Miscellaneous Intersections with No Signal by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (0.8) | Dusk (1.5) | Daylight (4.0) | Dark: No Streetlight (0.2) | Dark: Streetlight (1.0) |
| Peak (4.1) | 1.2 | 4.6 | 4.5 | 1.7 | 6.4 |
| Off Peak (1.8) | 0.2 | 1.6 | 2.8 | 0.1 | 0.9 |

| Table 2a.32: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Crossroad Intersections with No Signal by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (3.9) | Dusk (7.0) | Daylight (15.6) | Dark: No Streetlight (1.8) | Dark: Streetlight (2.7) |
| Peak (15.0) | 5.5 | 13.9 | 16.1 | 14.1 | 18.3 |
| Off Peak (7.1) | 1.0 | 7.6 | 10.8 | 1.7 | 2.5 |

| Table 2a.33: Crashes Per Mile Per Year for all Michigan HSIS Crashes at "T", or "Y" Intersections with No Signal by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (3.5) | Dusk (6.0) | Daylight (14.3) | Dark: No Streetlight (1.8) | Dark: Streetlight (2.8) |
| Peak (14.0) | 4.9 | 15.1 | 14.9 | 12.8 | 19.7 |
| Off Peak (6.7) | 0.9 | 6.6 | 9.9 | 1.6 | 2.6 |

| Table 2a.34: Crashes Per Mile Per Year for all Michigan HSIS Crashes at "T", or "Y" Intersections with No Signal and No Auxiliary Lanes by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (3.4) | Dusk (5.9) | Daylight (14.0) | Dark: No Streetlight (1.7) | Dark: Streetlight (2.8) |
| Peak (13.6) | 4.8 | 14.7 | 14.5 | 12.3 | 19.2 |
| Off Peak (6.5) | 0.9 | 6.4 | 9.7 | 1.6 | 2.6 |

| Table 2a.35: Crashes Per Mile Per Year for all Michigan HSIS Crashes at "T", or "Y" Intersections with No Signal and Auxiliary Lanes by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (7.2) | Dusk (9.5) | Daylight (22.8) | Dark: No Streetlight (2.7) | Dark: Streetlight (4.3) |
| Peak (26.7) | 10.2 | 28.5 | 28.1 | 28.6 | 34.9 |
| Off Peak (10.4) | 2.0 | 10.4 | 15.8 | 2.4 | 3.8 |

| Table 2a.36: : Crashes Per Mile Per Year for all Michigan HSIS Crashes at Crossroad Intersections with No Signal and No Auxiliary Lanes by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (3.7) | Dusk (6.6) | Daylight (15.1) | Dark: No Streetlight (1.7) | Dark: Streetlight (2.7) |
| Peak (14.5) | 5.3 | 13.3 | 15.5 | 13.5 | 17.3 |
| Off Peak (6.8) | 1.0 | 7.2 | 10.5 | 1.6 | 2.5 |

| Table 2a.37: : Crashes Per Mile Per Year for all Michigan HSIS Crashes at Crossroad Intersections with No Signal and Auxiliary Lanes by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (5.4) | Dusk (12.1) | Daylight (23.0) | Dark: No Streetlight (3.4) | Dark: Streetlight (3.9) |
| Peak (22.4) | 7.9 | 22.5 | 23.7 | 21.8 | 33.2 |
| Off Peak (10.7) | 1.3 | 13.2 | 15.9 | 3.2 | 3.5 |

| Table 2a.38: Crashes Per Mile Per Year for all Michigan HSIS Crashes at "T" or "Y" Intersections with Either a Fixed, Semi-, or Fully-Actuated Signal by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (14.4) | Dusk (31.1) | Daylight (80.7) | Dark: No Streetlight (3.3) | Dark: Streetlight (17.4) |
| Peak (78.7) | 23.6 | 79.9 | 85.4 | 45.1 | 114.8 |
| Off Peak (34.9) | 1.9 | 33.9 | 55.9 | 2.7 | 16.0 |

| Table 2a.39: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Merge/Diverge or Miscellaneous Intersections with Either a Fixed, Semi-, or Fully-Actuated Signal by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (3.8) | Dusk (5.8) | Daylight (26.4) | Dark: No Streetlight (1.0) | Dark: Streetlight (5.9) |
| Peak (25.9) | 5.3 | 26.4 | 29.4 | 2.8 | 30.1 |
| Off Peak (11.5) | 1.0 | 6.3 | 18.3 | 1.0 | 5.6 |

| Table 2a.40: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Merge/Diverge Intersections with No Signal by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (0.2) | Dusk (0.5) | Daylight (1.0) | Dark: No Streetlight (0.1) | Dark: Streetlight (0.2) |
| Peak (1.0) | 0.3 | 0.9 | 1.0 | 1.0 | 1.1 |
| Off Peak (0.4) | 0.1 | 0.5 | 0.7 | 0.1 | 0.2 |

| Table 2a.41: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Miscellaneous Intersections with No Signal by Light Condition, Peak/Off Peak, and these Variables Combined. | | | | | |
|---|---|---|---|---|---|
| | Dawn (2.7) | Dusk (4.5) | Daylight (13.1) | Dark: No Streetlight (0.4) | Dark: Streetlight (3.4) |
| Peak (13.6) | 4.0 | 15.7 | 14.7 | 4.0 | 22.1 |
| Off Peak (5.9) | 0.6 | 4.9 | 9.0 | 0.4 | 3.1 |

### 2.3.3. Freeway Interchange Elements

Figure 2a.4 shows the top-level structure of the look-up tables for rural Michigan freeway interchange elements. Figure 2a.5 shows the top-level structure of the look-up tables for urban Michigan freeway interchange elements. Because the categories were pre-defined by us (rather than by segmentation analysis), several categories branch from the top-level boxes. Note that in each figure, the top box (number 42) is the same, indicating that the two look-up table structures are linked together. Within each box, the variables that uniquely define the box are indicated; "R" equals the crash rate (number of crashes/year/mile); and "N" equals the number of elements on which the rate for that box was calculated. As indicated earlier, the HSIS Michigan Interchange file contained very little data for our purposes. Many of the rates, therefore, are based on very low numbers of interchange elements.

As with the segments and intersections, depending upon the information available to the system at the given moment, the look-up table pointer will move down a branch of the top-level structure until it reaches a terminal box (shown with thick outlines) or a box in which the SAVE-IT system does not have the information for the pointer to move to the next level.  Once this occurs, the look-up table pointer would move to the look-up table associated with the final box (Tables 2a.42 - 2a.108). These tables contain crash rates based upon the box variables.  Only two levels of lighting conditions (dark, light) were available in the database.

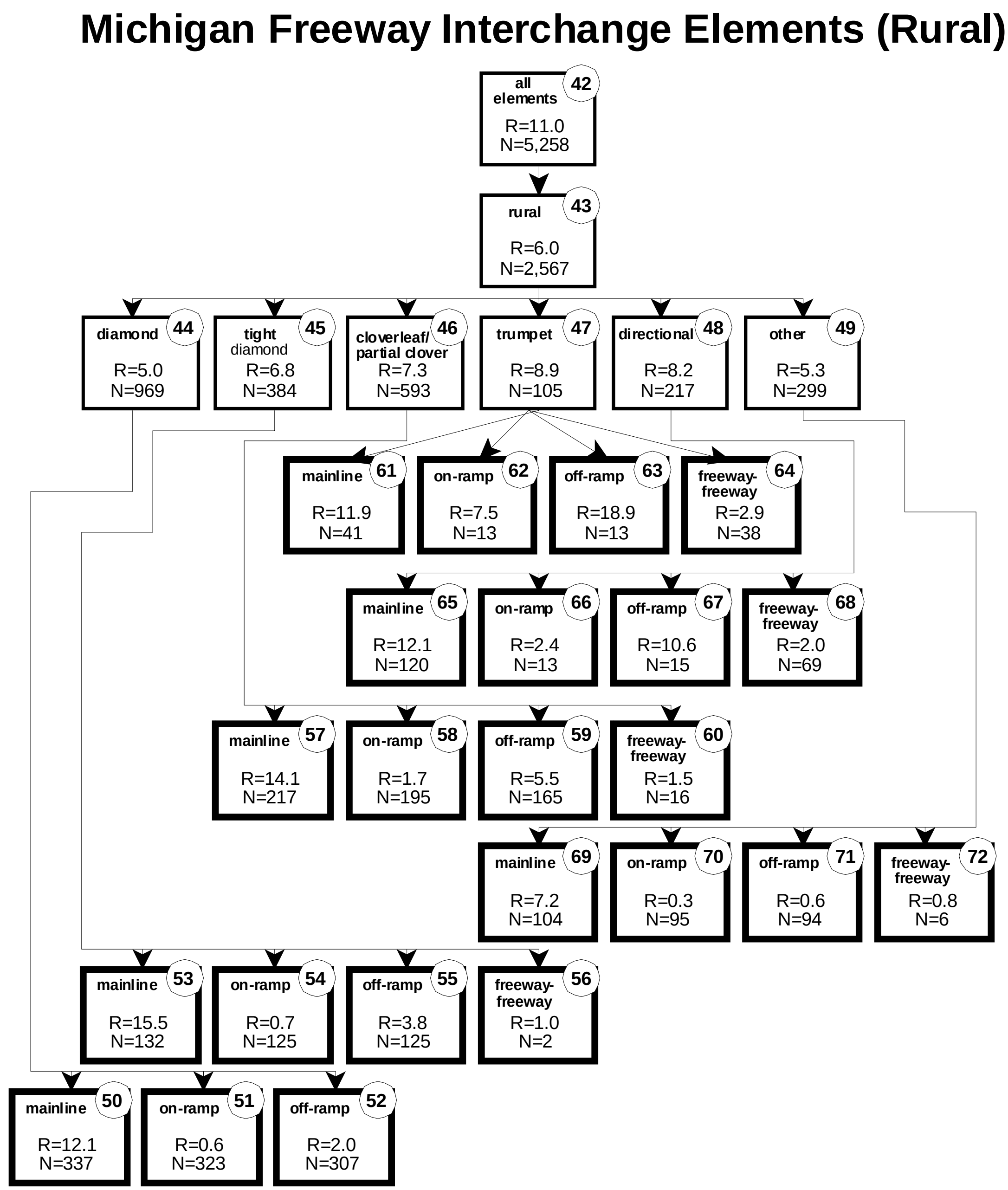


**Figure 2a.4. Top level crash-rate look-up table structure for rural freeway interchange elements in Michigan.**

# Michigan Freeway Interchange Elements (Urban)

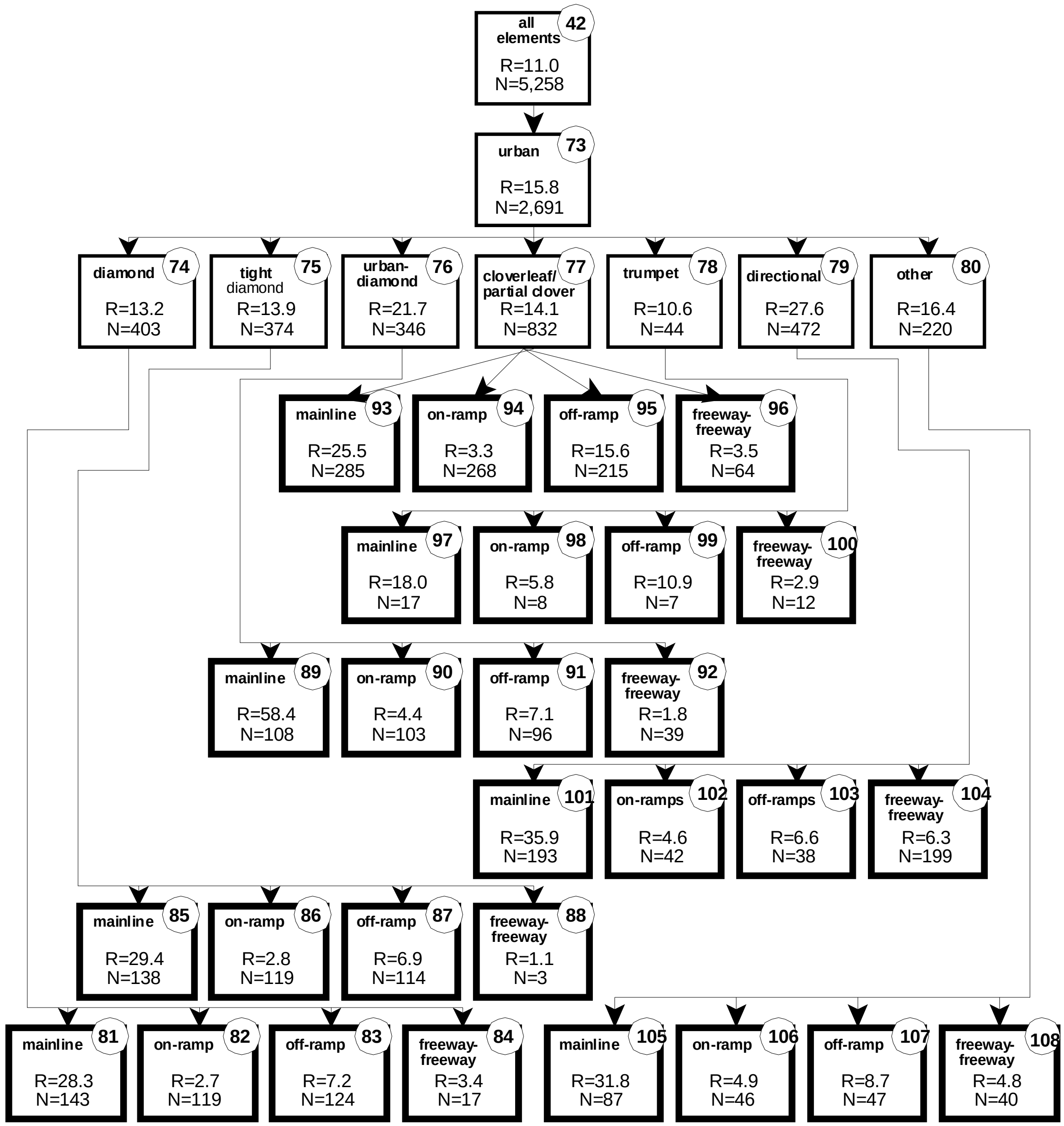


**Figure 2a.5. Top level crash-rate look-up table structure for urban freeway interchange elements in Michigan.**

| Table 2a.42: Crashes Per Mile Per Year for all Michigan HSIS Crashes at All Freeway Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 14.8 | 9.9 |

| Table 2a.43: Crashes Per Mile Per Year for all Michigan HSIS Crashes at All Rural Freeway Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 6.4 | 5.7 |

| Table 2a.44: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 5.8 | 4.4 |

| Table 2a.45: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Tight Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 7.4 | 6.4 |

| Table 2a.46: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Cloverleaves and Partial Cloverleaves by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 5.8 | 4.4 |

| Table 2a.47: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Trumpets by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 9.5 | 8.5 |

| Table 2a.48: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Directional Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 8.4 | 8.0 |

| Table 2a.49: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural “Other” Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 3.4 | 2.3 |

| Table 2a.50: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Diamond Mainline Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 14.8 | 9.9 |

| Table 2a.51: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Diamond On-Ramp Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 0.4 | 0.8 |

| Table 2a.52: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Diamond Off-Ramp Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 1.6 | 2.3 |

| Table 2a.53: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Tight Diamond Mainline Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 17.7 | 13.8 |

| Table 2a.54: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Tight Diamond On-Ramp Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 0.7 | 0.7 |

| Table 2a.55: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Tight Diamond Off-Ramp Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 3.3 | 4.3 |

| Table 2a.56: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Tight Diamond Freeway-to-Freeway Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 0.8 | 1.2 |

| Table 2a.57: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Mainline Cloverleaves and Partial Cloverleaves by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 15.1 | 13.3 |

| Table 2a.58: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural On-Ramp Cloverleaves and Partial Cloverleaves by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 1.7 | 1.7 |

| Table 2a.59: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Off-Ramp Cloverleaves and Partial Cloverleaves by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 3.2 | 7.4 |

| Table 2a.60: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Freeway-to-Freeway Cloverleaves and Partial Cloverleaves by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 1.3 | 1.6 |

| Table 2a.61: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Mainline Trumpets by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 14.4 | 9.9 |

| Table 2a.62: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural On-Ramp Trumpets by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 6.8 | 8.0 |

| Table 2a.63: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Off-Ramp Trumpets by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 14.5 | 22.5 |

| Table 2a.64: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Freeway-to-Freeway Trumpets by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 3.4 | 2.4 |

| Table 2a.65: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Mainline Directional Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 13.1 | 11.3 |

| Table 2a.66: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural On-Ramp Directional Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 3.2 | 1.8 |

| Table 2a.67: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Off-Ramp Directional Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 4.2 | 15.7 |

| Table 2a.68: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Freeway-to-Freeway Directional Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 2.1 | 1.9 |

| Table 2a.69: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Mainline “Other” Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 9.1 | 5.8 |

| Table 2a.70: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural On-Ramp “Other” Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 0.2 | 0.3 |

| Table 2a.71: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Off-Ramp “Other” Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 0.6 | 0.6 |

| Table 2a.72: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Rural Freeway-to-Freeway “Other” Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 1.0 | 0.6 |

| Table 2a.73: Crashes Per Mile Per Year for all Michigan HSIS Crashes at All Urban Freeway Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 13.0 | 18.0 |

| Table 2a.74: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 11.1 | 15.0 |

| Table 2a.75: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Tight Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 12.0 | 15.4 |

| Table 2a.76: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Urban-Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 17.5 | 25.0 |

| Table 2a.77: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Cloverleaves and Partial Cloverleaves by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 11.0 | 16.6 |

| Table 2a.78: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Trumpets by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 11.7 | 9.6 |

| Table 2a.79: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Directional Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 15.7 | 20.3 |

| Table 2a.80: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban “Other” Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 12.7 | 19.3 |

| Table 2a.81: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Mainline Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 25.3 | 30.8 |

| Table 2a.82: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban On-Ramp Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 2.0 | 3.3 |

| Table 2a.83: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Off-Ramp Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 4.5 | 9.4 |

| Table 2a.84: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Freeway-to-Freeway Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 2.6 | 4.2 |

| Table 2a.85: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Mainline Tight Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 26.4 | 31.8 |

| Table 2a.86: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban On-Ramp Tight Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 3.2 | 3.3 |

| Table 2a.87: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Off-Ramp Tight Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 5.0 | 8.5 |

| Table 2a.88: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Freeway-to-Freeway Tight Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 2.0 | 0.4 |

| Table 2a.89: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Mainline Urban-Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 48.9 | 65.9 |

| Table 2a.90: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban On-Ramp Urban-Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 2.6 | 5.8 |

| Table 2a.91: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Off-Ramp Urban-Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 5.0 | 8.8 |

| Table 2a.92: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Freeway-to-Freeway Urban-Diamond Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 0.6 | 2.7 |

| Table 2a.93: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Mainline Cloverleaves and Partial Cloverleaves by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 23.2 | 27.4 |

| Table 2a.94: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban On-Ramp Cloverleaves and Partial Cloverleaves by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 2.6 | 3.9 |

| Table 2a.95: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Off-Ramp Cloverleaves and Partial Cloverleaves by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 8.0 | 21.6 |

| Table 2a.96: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Freeway-to-Freeway Cloverleaves and Partial Cloverleaves by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 2.4 | 4.4 |

| Table 2a.97: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Mainline Trumpets by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 22.2 | 14.7 |

| Table 2a.98: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban On-Ramp Trumpets by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 5.6 | 6.0 |

| Table 2a.99: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Off-Ramp Trumpets by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 7.0 | 14.1 |

| Table 2a.100: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Freeway-to-Freeway Trumpets by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 3.8 | 2.3 |

| Table 2a.101: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Mainline Directional Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 30.1 | 40.4 |

| Table 2a.102: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban On-Ramp Directional Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 4.4 | 4.7 |

| Table 2a.103: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Off-Ramp Directional Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 5.8 | 7.2 |

| Table 2a.104: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Freeway-to-Freeway Directional Elements by Light Condition. | | |
|---|---|---|
| | Dark | Light |
| | 6.0 | 6.6 |

| Table 2a.105: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Mainline "Other" Elements by Light Condition. | | |
|---|---|---|
| | **Dark** | **Light** |
| | **28.8** | **45.7** |

| Table 2a.106: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban On-Ramp "Other" Elements by Light Condition. | | |
|---|---|---|
| | **Dark** | **Light** |
| | **4.2** | **5.6** |

| Table 2a.107: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Off-Ramp "Other" Elements by Light Condition. | | |
|---|---|---|
| | **Dark** | **Light** |
| | **8.5** | **16.3** |

| Table 2a.108: Crashes Per Mile Per Year for all Michigan HSIS Crashes at Urban Freeway-to-Freeway "Other" Elements by Light Condition. | | |
|---|---|---|
| | **Dark** | **Light** |
| | **4.2** | **5.3** |

## 2.4. DISCUSSION

As discussed previously, this document had two purposes. The first was to develop crash-rate look-up tables to determine is they could be used by SAVE-IT as a surrogate measuring driving task demand. The second purpose was to draw conclusions about the use of crash probabilities based on crash rates as an indicator of driving task demand and discuss validation needs and other future research.

### 2.4.1. Crash-Rate Look-up Tables

We analyzed three categories of Michigan HSIS crash data: Segments, intersections, freeway interchange elements. The former two categories were analyzed using segmentation analysis. Because of the relatively small number of descriptive variables contained in the freeway interchange file, segmentation analysis could not be used. Instead, we calculated crashes rates on all available variables, despite the fact that many had small Ns and/or large variances.

For all analyses other than those in the Appendix, we omitted traffic volume from the analyses because this variable was highly correlated with crashes and dominated the segmentation splits. The fact that volume is highly correlated with crashes (and, therefore, driving task demand) is supported by simulator research (see e.g., Mourant & Ge,1997). In this research, visual demand increased with increases in traffic volume.

For the road segments, the segmentation analysis produced binary splits on just five of the nine predictive variables used in the SEARCH model, indicating that the splits on these five variables accounted for a greater amount of variance than splits on the other variables would have. Thus, the segment look-up tables do not include the width of the left or right shoulder, the speed limit, the presence of passing lanes, or degree of curvature. This result should not be interpreted to mean that crash rates did not vary as a function of these variables; it simply indicates that they varied less than for the variables on which the SEARCH model produced splits.

Considering Figure 2a.2 and Tables 2a.1 – 2a.20, it appears that there is some face validity between the calculated crash rates and what one might expect for driving task demand. Crash rates were higher on urban than on rural segments; on principal rather than non-principal segments; on multi-lane roads rather than on 2-lane roads; during peak than during off peak hours; during dawn, dusk, and dark with no street lighting than for daylight or dark but lighted conditions; and for peak period for dusk, dawn, and dark/no street lighting than for these same lighting conditions during off peak times. Counter to what one would expect, rural segments with lanes greater than 11 ft tended to have higher crash rates than rural segments with lanes 11 ft wide or less (see boxes 6 and 7; Figure 2a.2). However, it is important to keep in mind that both of these boxes split further showing that the effect of wide lanes is largely based upon the high crashes rates for 3-5 lanes rural roads. When the terminating boxes for the branch containing box 6 (lane width = 9-11 ft) are examined, one finds that crash rates are higher for 9-10 ft wide lanes than for 11 ft wide lanes. This finding is consistent with visual demand studies in a simulator (Courage, Milgram, & Smiley, 2000; Senders et al., 1967; Van der Horst & Godthelp, 1989)

The segmentation analyses for intersections used four predictive variables and produced splits on three of these variables (type of intersection, signal type, and presence of auxiliary lanes). No splits were found for the number of legs, although much of this variability was probably accounted for by intersection type.

Consideration of Figure 2a.3. and Tables 2a.21 - 2a.39 shows that the results have some face validity. Crash rates were higher for intersections with a signal than for those without a signal; were higher when the signal was something other than a flasher; were higher for crossroad, “T” and “Y” intersections than for merge/diverge or miscellaneous intersections; were higher when turn lanes were present than when turn lanes were not present; and were higher for peak than off peak times. The crash rates for lighting conditions are counterintuitive at first blush; with rates highest for daylight conditions and for dark/lighted conditions during peak times. One must keep in mind, however, that most intersection traffic occurs during daylight conditions and that intersections are lighted usually because of high traffic volumes. Thus, these trends most likely reflect traffic volumes. Finally, crash rates for intersections were substantially higher than the rates calculated for segments.

The freeway interchange element file contained little information about the characteristics of the interchange elements that would be meaningful in segmentation analysis. Instead, crash rates were simply calculated as a function of the available variables. As seen in Figures 2a.4 and 2a.5, we split the data first on urban vs. rural, then on interchange type, and finally on element type. These results should be interpreted with caution since many of the crash rates were calculated on a small number of elements. For each box in these figures we also calculated the rate by the box variables and light vs. dark lighting conditions (Tables 2a.42 – 2a.108).

The freeway interchange results also have some face validity. As expected, urban rates were higher than rural rates overall. For rural areas, trumpet and directional intersections had the highest crash rates followed closely by cloverleafs/partial cloverleafs and tight-diamonds. As can be seen in Figure 2a.1, trumpet, directional and cloverleaf interchanges are complex. The simplest, and most common interchange, a diamond, had the lowest crash rate. For urban interchanges, crash rates were highest for directional and urban-diamond interchanges, both complex interchanges. Because trumpet interchanges are not common in urban areas, if we exclude this interchange type, the diamond interchange has the lowest crash rate and seems that it would also be the least demanding of attention. For both rural and urban interchanges, the mainline elements had the highest crash rates followed distantly by off-ramps. On mainline elements, the driver has fairly complex interactions with other traffic, such as merging while braking or accelerating, as well as watching out for other drivers who are doing the same thing. It makes sense that off-ramps would have higher crash rates than on-ramps or freeway-to-freeway elements, since the driver is required to decelerate appropriately while tracking the deceleration of other traffic. The crash rates for light vs. dark periods showed that rural crashes were more frequent during dark times while the opposite was true for urban freeway interchange elements. This trend may simply reflect traffic volumes. Comparing the interchange crash rates to segments and intersections, we find that the crashes rates for both intersections and interchanges are about the same.

## 2.4.2. Conclusions

Based upon the present results, it appears that crash rates are likely to be an inadequate surrogate measure of driving task demand, due primarily to the limitations of this approach. First, crash data are notoriously noisy; that is, errors in coding and changes in how crashes are coded, can lead one to incorrect conclusions. Second, crashes are relatively infrequent events, meaning that many years of data need to be utilized to obtain meaningful results. Changes in the roadway, vehicle, policy, or enforcement over the years can alter crash rates without altering driving task demand. Third, there is no "perfect" crash database for specific purpose of this task. We selected the Michigan HSIS crash database because this database contained the best roadway and environmental data. Unfortunately, the data come only from Michigan trunklines, which are mostly rural 2-lane roads. The presented results, therefore, may be less accurate for urban roads. Fourth, as we have already pointed out, crashes occur in high traffic volume areas and, therefore, on roads that are designed to carry high volumes of traffic. Traffic volume in the Michigan HSIS database is based on an average taken over the entire year. As such, use of this variable directly is the present analyses would not yield useful predictions of moment-to-moment driving task demand. A better measure of traffic would be the current traffic density. If the SAVE-IT system could estimate density on a real-time basis, this would be an important input for predicting driving task demand. Fifth, for the crash rates to be calculated, it is necessary to correct them for exposure. Such exposure was not feasible to obtain for certain variables such as weather. While HSIS does contain weather information, we did not know what weather each segment was exposed to each year, precluding the use of weather in this study. Finally, we attempted to cover all types of Michigan roadways by analyzing segment, intersection, and interchange crashes. In order to make the crash rates from each of these categories comparable (i.e., crashes per year per mile) we had to estimate the lengths of both intersections and freeway interchange elements (segment length is found in HSIS). The crash rates for intersections and interchanges are only as accurate as our estimates of length.

Many of the variables that the segmentation analysis found to be most important in traffic crashes (such as rural vs. urban, functional road classification, intersection type, and interchange type) dictate that the SAVE-IT system have access to a global position system (GPS) mapped to a road network with geographical information system (GIS) capabilities. Without such capabilities, it is difficult to see how the system would sense upcoming intersection or interchange types, whether or not the area is rural, and so on. All of these variables can be mapped onto roadways in current GIS applications.

It is unknown at this time how to convert the crash rates reported here into levels of driving task demand. To do this, it is necessary to conduct a validation study using either a simulator and/or an on-the-road study. We attempted to validate these data using SAVE-IT simulator results from Cullinane and Green (2004). To this end, we conducted a preliminary validation study to see how crash probabilities relate to a measure of visual demand in a simulator (Cullinane & Green, 2004). The basic idea was to compare measures of visual occlusion (Senders et al., 1967) with calculated crash probabilities on matching roadways.

As described in Cullinane and Green (2004), the simulator study utilized 2-lane roads with 11.8 ft (3.6 meters) lane widths with good roadsides Three curve radii were present: 0 m (straight segment; 0 deg of curvature); 200 m (4-5 deg of curvature); and 400 m (8-9 deg of curvature). All curves changed the direction of the path by 90 deg. While there were other vehicles on the road, the simulated traffic density was quite low. Subjects were instructed to drive at speeds of 55 and 65 mph.

In order to match these simulator conditions to Michigan trunklines in HSIS, it was necessary to find segments on 2-lane rural roads with the corresponding curvature and change of direction. Because 90 deg changes of direction are very uncommon for Michigan trunklines, we found too few matching segments to calculate reliable crash probabilities. Thus, we could not use this simulator study to validate our results.

## 2.5. REFERENCES


American Association of State Highway and Transportation Officials (2001). *A Policy on Geometric Design of Highways and Streets*. AASHTO: Washington, DC.

Boer, E. R. (2001). Behavioral entropy as a measure of driving performance. *Proceedings of the First International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design,* 225-229.

Cullinane, B. & Green, P.A. (2004). *Visual Demand of Curves and Fog-Limited Sight Distance And Its Relationship to Brake Response Time*. Delphi Delco Electronics/US Department of Transportation (Volpe Center).

Courage, C., Milgram, P., & Smiley, A. (2000). An investigation of attentional demand in a simulated driving environment. In *Proceedings of the IEA 2000/HFES 2000 Congress*. (pp. 3-336 - 3-339). EHES: Santa Monica, CA.

Eby, D.W. & Kostyniuk, L.P. (2003a). *Crashes And Driver Distraction: A Review of Databases, Crash Scenarios, and Distracted-Driving Scenarios*. Delphi Delco Electronics/US Department of Transportation (Volpe Center).

Eby, D.W. & Kostyniuk, L.P. (2003b). *A Literature Review of Driving Task Demand*. Delphi Delco Electronics/US Department of Transportation (Volpe Center).

Federal Highway Administration (2000). *Manual of Uniform Traffic Control Devices*. US Department of Transportation: Washington, DC.

Harwood, D. W., Council, F. M., Hauer, E., Hughes, W. E. & Vogt, A. (2000). *Prediction of the Expected Safety Performance of Rural Two-Lane Highways.* (Report No. FHWA-RD-99-207). U.S. Department of Transportation: Washington, DC.

Michigan Department of Transportation (1998). *Geometric Design Guide*. Geometric Engineering Unit: Lansing MI.

Morgan J.M., Solenberger P.W., Van Eck N.A., & Nagara P.R. (2003). SEARCH: Software for Exploring Data Structure. Survey Research Center, Institute for Social Research, University of Michigan: Ann Arbor, MI.

Mourant, R.R. & Ge, Z. (1997). Measuring attentional demand in a virtual environments driving simulator. In *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting*. (pp. 1268-1272). HFES: Santa Monica, CA.

Senders, J. W.; Kristofferson, A. B.; Levison, W. H.; Dietrich, C. W.; Ward, J. L. (1967). The attentional demand of automobile driving. *Highway Research Record* **195**, 15-33.

Sonquist, J.A., Baker, E.L. & Morgan, J.N. (1973). *Searching for Structure* (Rev. Ed.)

University of Michigan Institute for Social Research: Ann Arbor, MI.

Van der Horst, R. & Godthelp, H. (1989). Measuring road user behavior with an instrumented car and an outside-the-vehicle video observation technique. *Transportation Research Record*, **1213**, 72-81.

Versace, J. (1960). Factor analysis of roadway and accident data. *Highway Research Board Bulletin, **240***, 24-3.

Wang, J.-S., Knipling, R.R., & Goodman, M.J. (1996). The role of driver inattention in crashes: New statistics from the 1995 Crashworthiness Data System. In *40th Annual Proceedings Association for the Advancement of Automotive Medicine*. (pp 377-392). AAAM: Des Plaines, IA.

# 2.6. APPENDIX A

As discussed in Sections 2.2.2.1 – 2.2.2.2, the traffic volume variable (AADT) was removed from the segmentation analyses because the binary splits were dominated by this variable, washing out the effects of the other variables. In order to further explore the effect of traffic volume on crash rates, we conducted exploratory analyses using the AADT variable from HSIS to calculate crash rates per mile per year per 1,000 vehicles on the segmentation splits derived without use of AADT (Figures 2a.2 and 2a.3). This analysis was straightforward for segments, since AADT is given in the dataset for most segments. For intersections, AADT is only given for the Michigan trunkline of the intersection; that is, we do not have volume data on the crossroad. Because there is no information on the crossroad, we used the AADT value for the trunkline for calculation of intersection rates. We were unable to perform these analyses for freeway interchanges because AADT is only given for the mainline element. Without making extensive and questionable estimates of volume for the other elements, calculation of crash rates by volume for freeway interchanges cannot be conducted.

Figure 2a.6 shows the crashes per mile per year per 1000 vehicles for segment groups defined by the segmentation analysis splits found in Section 2.3.1. Because we have no information on traffic volume by peak/off peak or by lighting condition, the boxes in this figure are not associated with a table and are consequently not numbered. A comparison of this figure to Figure 2a.2 showed opposite trends. When volume was included in the rate, rural crashes were nearly twice as likely as urban crashes, non-freeway crashes were more likely than freeway crashes, and crashes on 2-lane roads were more likely than on multi-lane roads. Lane width did not seem to have differential effects on crash rates.

Figure 2a.7 shows the crashes per mile per year per 1000 vehicles for intersection groups defined by the segmentation analysis splits found in Section 2.3.2. Again, because we have no information on traffic volume by peak/off peak or by lighting condition, the boxes in this figure are not associated with a table and are not numbered. Quick comparison of this figure to Figure 2a.3 shows surprisingly similar crash rate trends. Careful analysis, however, shows that the relative difference is reduced between splits that should be influenced by the inclusion of volume in the calculation of rates. For example, the difference in crash rates for no signal and signal in Figure 2a.3 is 5.8 (i.e., the rate was 5.8 times higher for intersections with a signal than without). When intersection AADT was included in the calculation this difference was only 3.3. Since signalized intersections should carry more traffic than non-signalized intersections on both the trunkline and the crossroad, the unavailability of crossroad volumes (and our subsequent exclusion of them in these analyses) means that the crash rates for signalized intersections have been overestimated. Thus, it is likely that the lack of difference in trends when volume is included in the calculation of rates can be mainly explained by the lack of volume data on the intersection crossroad. We conclude, therefore, that the intersection rates reported in Figure 2a.7 are probably not useful.

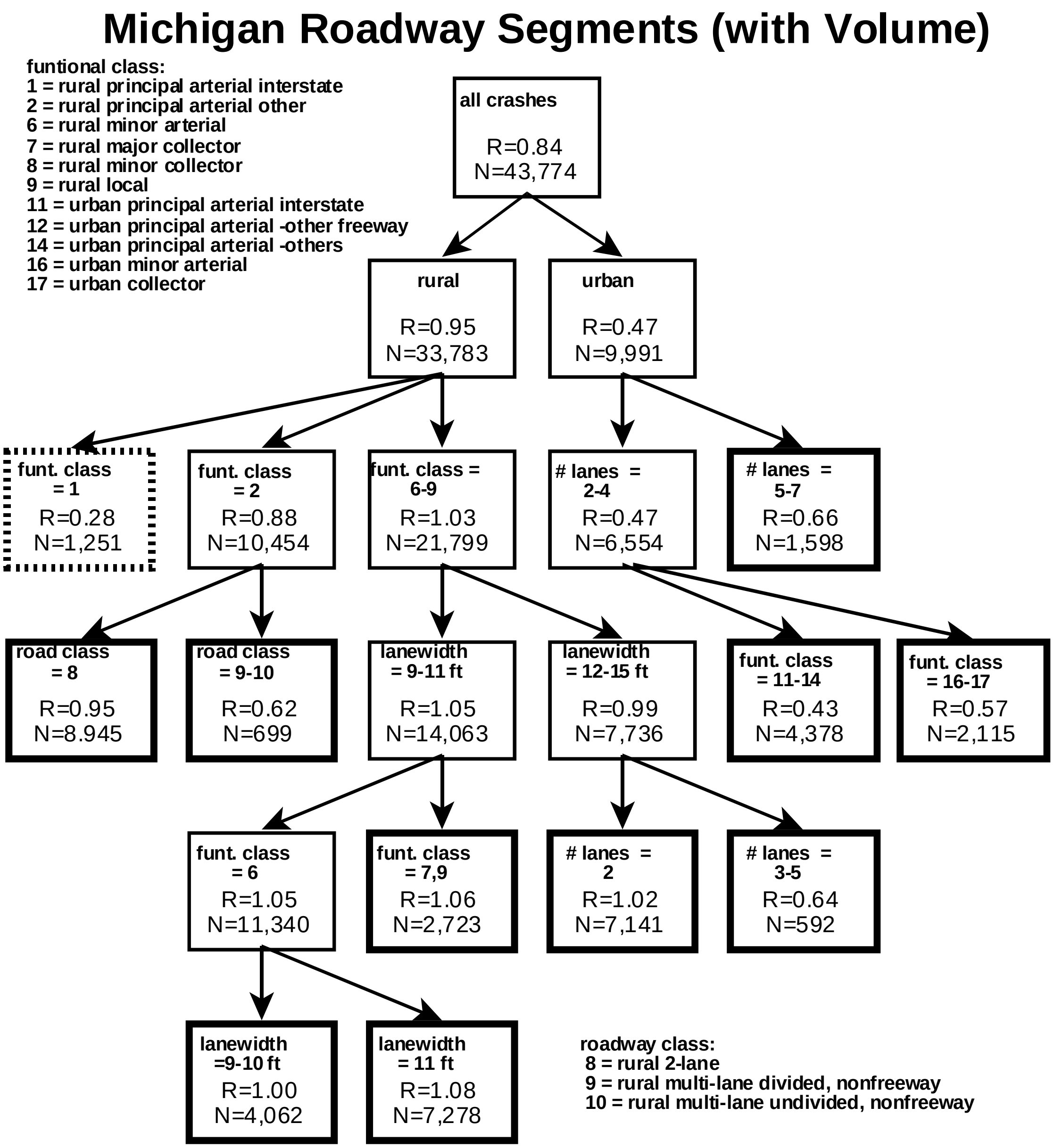


**Figure 2a.6. Crash-rate (crashes/1000 vehicles/mile/year) look-up table for roadway segments in Michigan.**

# Michigan Intersections (with Volume)

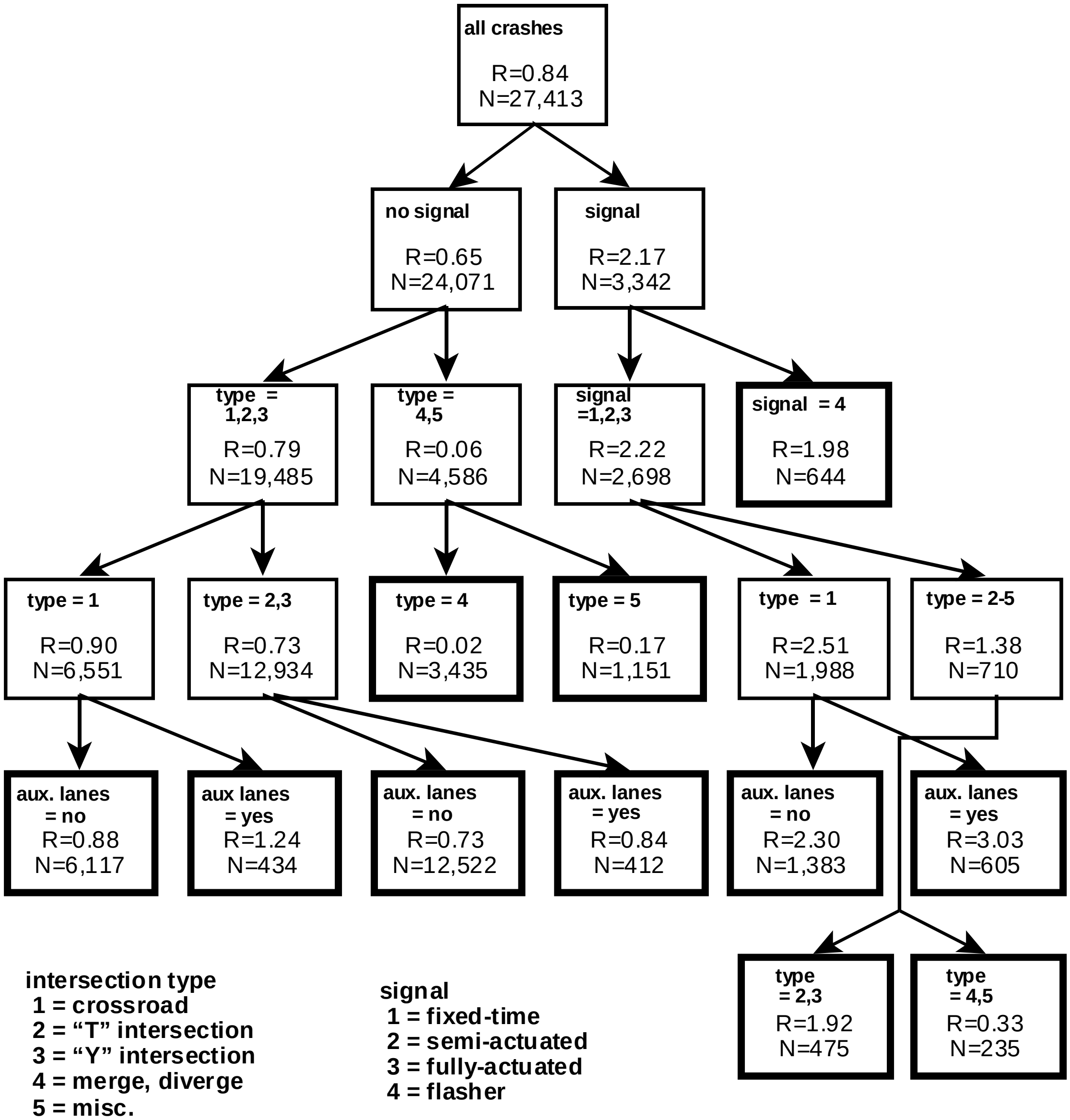


**Figure 2a.7. Crash-rate (crashes/1000 vehicles/mile/year) look-up table for roadway intersections in Michigan.**

As a final way to investigate the effects of the traffic volume variable on crash rates, we conducted a new segmentation analysis using crash rates normalized by AADT (i.e., # crashes/1,000 veh mile/year). All the segment descriptors that were used in the previous analyses were used as predictor variables including AADT; that is, traffic volume was included in the dependent variable and among the predictor variables for this analysis.

The results are shown in Figure 2a.8. As shown in this figure, traffic volume still dominates the segmentation analyses, even when the dependent variable is a rate based on traffic volume. Although there are some splits by elements of road geometry (lane width, left shoulder width, and curve) and operation (speed limit) it is difficult to identify the type of roads in each of the binary splits. The main reason for this finding is that road design and the traffic volume that a road segment carries are closely related. Thus, whenever volume is among the predictor variables of a segmentation analysis of this type, variables such as functional class, roadway class, and even rural/urban area will not appear in the splits.

On the other hand, information about the rural/urban designation, functional class, and roadway class carries with it much information about the road design, its operation, and the volume of traffic that it carries. Thus, if volume is to be included in segmentation analysis, this argues for using crash rates per mile as the dependent variable, and segmenting using variables that best describe the bundles of road design and operation characteristics. Crash rates per vehicle can then be obtained for the final groupings of road segments as was done in Figure 2a.6.

## Michigan Roadway Segments
## (Segmentation on # crashes/1000 veh mile/year)

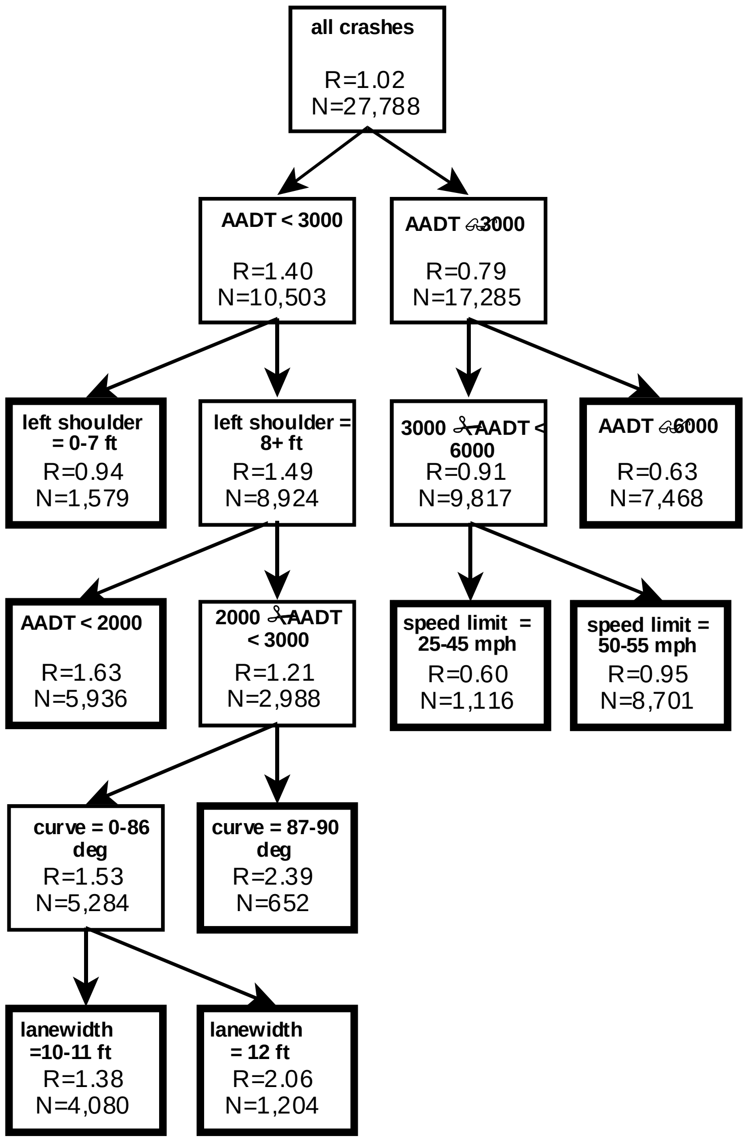


**Figure 2a.8. Crash-rate look-up table for roadway segments in Michigan, with analyses conducted on crash rates normalized by AADT.**